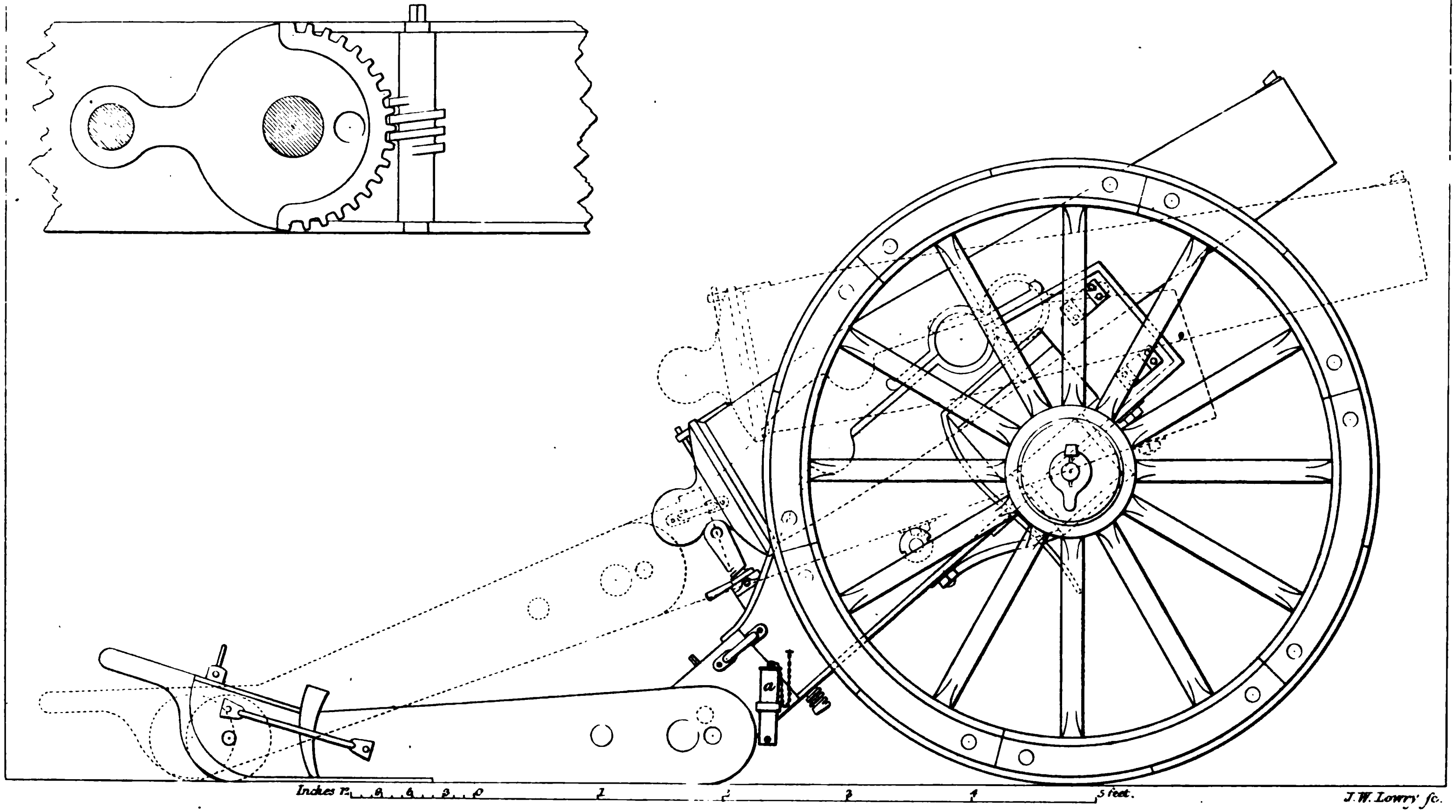

RIFLED
ORDNANCE

FRONTISPIECE



J. W. Lowry fc.

RIFLED ORDNANCE.

A PRACTICAL TREATISE

ON

THE APPLICATION

OF

THE PRINCIPLE OF THE RIFLE

TO

GUNS AND MORTARS

OF EVERY CALIBRE.

TO WHICH IS ADDED

A NEW THEORY OF THE INITIAL ACTION AND FORCE OF FIRED GUNPOWDER.

(Read before the Royal Society, 16th December, 1858.)

FOURTH EDITION, *revised and enlarged.*

BY LYNALL THOMAS, F.R.S.L.

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1859.

TO

HIS ROYAL HIGHNESS

THE DUKE OF CAMBRIDGE, K.G.

&c. &c. &c.

COMMANDER-IN-CHIEF OF THE BRITISH ARMY,

This small Treatise

IS, BY KIND PERMISSION,

MOST RESPECTFULLY DEDICATED BY

HIS ROYAL HIGHNESS'S

FAITHFUL HUMBLE SERVANT,

THE AUTHOR.

PREFATORY REMARKS.

In a little work lately written by a Foreign Artillery Officer of distinction,* the author has entered into a mathematical investigation of many of the circumstances attending the flight of elongated projectiles, which I had previously endeavoured to explain in popular language, in a former edition of this treatise (published anonymously), as well as in a pamphlet "On the Influence which the Size of the Projectile has upon the Turn of the Rifling," which is now incorporated in this work.

Lieut.-General von Rouvroy appears, however, to have fallen into the almost universal error of estimating the resistance of the air, which shot of different diameters suffer in passing through equal spaces (all other circumstances, as form, density, and initial velocity, being the same), as the *square* of the diameters; whereas, owing to the more sustained velocity of shot of increased diameter, the resistance increases in a much higher ratio. In consequence of this error, he

* Dynamische Vorstudien zu einer Theorie der gegogenen Feuerwaffen, von Generalleutnant und Commandant der Königlich Sächsischen Artillerie von Rouvroy—*Dresden*, 1858.

makes the length of the turn of the rifling vary in the proportion of the diameter of the shot, instead of (as it properly should be) as the square root of the diameter.

His calculations are, nevertheless, corroborative in many respects, of what I have advanced. He admits the general truth of the principle—first put forward by myself—that the rotary velocity to be given to shot of different diameters, or the length of turn for the rifling, depends solely upon the comparative pressure of the air upon the projectile.

But although General von Rouvroy has done me the honour to adopt the main features of my theory; and in some cases has made use of the same diagrams to illustrate it—in fact, I am aware that he wrote his little work, partly, if not entirely, in consequence of the two above-mentioned publications—he has, nevertheless, omitted (no doubt, unintentionally,) to make any acknowledgment to this effect.

As, however, I worked out the theory three or four years ago, from experiments carried on entirely by myself; and as a Lieutenant-General of Artillery is much more likely to be considered by the public as the *lender* than the *borrower* of any ideas on this subject, I am induced to offer these few remarks by way of explanation.

My attention has been recently directed to a statement made by Sir W. Armstrong at the United Service Institution, and reported in the *Mechanics' Magazine* for June 3rd of this year, to the effect, that elongated

projectiles have a greater range when they are fired in the air, than they would have if they were fired in a vacuum, or non-resisting medium. This statement bears at first sight so much resemblance to certain opinions which I have hazarded myself (*see* chapter "On the Range of Elongated Projectiles," page 147,*) that I take the opportunity afforded by a preface, to make those observations with reference to it, which I was precluded doing in the proper place, from the circumstance of the sheets being already in the press.

Sir W. Armstrong's remarks (as reported) are as follows:—"In a vacuum the trajectory would be the same whether the projectile were elongated or spherical, so long as the angle of elevation and the initial velocity were constant; but the presence of a resisting atmosphere makes this remarkable difference, that while it greatly shortens the range of the round shot it actually prolongs that of the elongated projectile, provided the angle of elevation do not exceed a certain limit, which in my experiments I have found to be about 6°. This appears at first very paradoxical, but it may be easily explained. The elongated shot, if properly formed and having a sufficient rotation, retains

* These opinions were written more than a year and a half ago, and were then merely conjectural, but have since been verified by experiment in a remarkable manner. They appear, however, at first sight, so paradoxical, that I hesitated about publishing them, until they were, in some degree, confirmed by practice.

the same inclination to the horizontal plane throughout its flight, and consequently acquires a continually-increasing obliquity to the curve of its flight. Now the effect of this obliquity is, that the projectile is in a measure sustained upon the air, just as a kite is supported by the current of air meeting the inclined surface, and the result is, that its descent is retarded so that it has time to reach to a greater distance."

The above remark, that the air "actually prolongs the flight of elongated projectiles," requires to be considerably qualified. This effect may perhaps be produced under certain circumstances; as for instance, when the weight or the length of the projectile is great in a certain proportion to its diametral surface,—when the *velocity* is limited—and other circumstances, which I shall allude to directly. Although Sir W. Armstrong may have remarked this peculiar effect in his 32 lb. or 18 lb. elongated projectiles (in the same manner as I noticed it myself with a 32 lb. projectile of three diameters in length—*see* note, page 91), I should hardly think that he had observed it in the case of elongated projectiles of smaller diameter, unless they were fired with a lower velocity than usual.

In the chapter "On the Range of Elongated Projectiles," the reader will observe that I have not gone quite so far as to assert that long projectiles actually have their range prolonged when fired in the air; I have merely hazarded the conjecture that, under certain

circumstances, such might possibly be the case. It cannot be positively asserted as a fact, until we know precisely what initial velocities these projectiles really acquire.

I supposed that it might be true, from the circumstance of finding that the ranges of long projectiles, of a certain size and form, varied in a greater degree (with the elevation) than they would do in a vacuum; as will be seen by referring to the results described in the note on page 91.

The full explanation of the manner in which the resistance of the air tends to lengthen the flight of a long projectile may be given as follows.—When a round projectile is passing through the air, the whole resistance to its flight* is in the direction of the tangent to the curve; but when a long projectile is used, a different result is obtained. For, in consequence of the well-known law of hydrodynamics that when a solid body strikes obliquely on a fluid mass, the resistance will be perpendicular to the surface of the solid; the resistance on the surface of an elongated shot, will no longer act in the direction of the tangent to the curve of flight; but the resultant of the pressures on the fore end and the under side, will act in a direction *above* the tangent to the curve; so that although the velocity of the projectile is diminished, it will be made to

* This is independent of the unequal action of the air on opposite sides of the shot, caused by its rotary motion.

describe a path rather less curved to the horizon than it would otherwise have done. Hence, in certain circumstances, as when the elevation of the gun is not very great, the range may be prolonged.

It will be noticed that Sir W. Armstrong considers that to be a properly formed shot, of which the axis remains parallel to itself during its flight; but I am convinced it will be found, that a preferable form of shot will be one that has the centre of gravity thrown forward, so that the shot will remain approximately a tangent to its trajectory throughout its flight. In this case, the loss of velocity will be much less than in the former, and at the same time the obliquity to the trajectory will be sufficient to call into play the sustaining power of the air.

A projectile which maintains its axis parallel to itself, might have a certain advantage when the gun has little or *no* elevation, because the obliquity to the curve of flight would not then be so prejudicial to the velocity of the projectile, and the whole of the pressure upon its under surface would tend to sustain its flight; but the time of flight, in this case (unless the gun were placed on an eminence), would be too small to admit of any great advantage being thus obtained. When, however, the angle of elevation is high, the "increasing obliquity to the curve of flight" tends to diminish the velocity more than to retard the descent of such a projectile; and its curve of flight and range are, in consequence, diminished.

Hence the effect which Sir W. Armstrong remarked in his experiments; that the prolongation of flight alluded to, was only observable when the angle of elevation was below 6°.

Sir W. Armstrong's concluding sentence, that "its (the projectile's) descent is retarded, so that it has *time* to reach to a greater distance," could hardly, I should think, have been carefully considered before it was uttered; for every person familiar with the theory of the motion of projectiles will see that by diminishing the velocity of a projectile after it has passed the apex of its curve, its time of flight is lengthened while its range is on the contrary diminished.

Further experiments will be required for ascertaining whether the forward position of the centre of gravity conduces as much to precision as to great range; of the latter there can be no doubt; and I believe it will be found that, at the higher elevations, projectiles constructed in this manner will achieve both greater range and greater accuracy than any other.*

* The results obtained with the shells, noticed at page 91, (the centre of gravity being, in their case, in a forward position,) were comparatively greater, when the elevation was as much as 10°, than those obtained with Armstrong's. And they would have been still greater if I could have had at my disposal (which was far from being the case,) the superior mechanical means possessed by Sir W. Armstrong, or Mr. Whitworth, for properly carrying the principle into practice. These are the first, and I believe the only, projectiles of a proper length, which have yet been success-

I have touched largely upon this point, because it is one which materially affects the construction of projectiles, and is, therefore, of the highest importance. The errors which frequently arise in these matters evince the necessity of securing the services of a superior mathematician in conducting experiments with rifled cannon and projectiles. Experiments with the ballistic pendulum are very much required for ascertaining the highest velocities which can be effectively used with elongated projectiles; since much is dependent on a knowledge of this matter. The quality of the powder for rifled cannon must also be the subject of numerous experiments. The necessity of these experiments cannot be too strongly urged.

The belief, that the greatest results are already attained, or are even attainable with guns constructed upon the breech-loading principle, is the great error which our service—from comparing the results produced by the Armstrong, with those only which are obtained with the ordinary, gun; as well as from a limited acquaintance with the subject—appears most likely to fall

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fully fired from a rifled cannon which does not load at the breech; and are therefore, probably, with the exception of Sir W. Armstrong's, the only projectiles with which the effect I have been remarking upon, could have been observed. From the high velocity maintained by these projectiles (about 1000 feet a second), it appears probable that too high a value has hitherto been assigned to the resistance of the air; the *terminal* velocity of these projectiles, (according to the ordinary computation,) not much exceeding 700 feet a second.

into at present. If the breech-loading principle is found, in actual service, to be unobjectionable, guns constructed upon this principle may prove advantageous for field-service; since the very effective kind of Shrapnell shell invented by Sir W. Armstrong, could not be used, perhaps, with equally good results, with any but a breech-loading gun; but it will be found that a superior effect is attainable with rifled cannon of a larger kind, when they are constructed upon a different principle.

The increase in the comparative weight of the breech-loading apparatus — the increased difficulty and danger attending the loading — their enormous cost — are all circumstances which militate against the use of large breech-loading cannon; so that the adoption of this principle would tend to restrict the general employment of rifled cannon to those of a comparatively small size only. It is, moreover, questionable whether built-up shells will uniformly stand the explosive force of a large charge of powder, without previously undergoing a modification which would tend to lessen their efficiency. With respect to range, impact, and accuracy at the higher elevations, the results obtained with breech-loading cannon will certainly not be superior to those which can be produced by other guns of equal weight.

It is not my intention to disparage Sir W. Armstrong's numerous and admirable inventions, but simply to question the advantage of the breech-loading prin-

ciple, especially when applied to large rifled cannon. The whole advantage of this principle may be summed up in three words,—absence of windage. Instead of devoting his experiments to the discovery of a means for *obviating* the effects of windage, Sir W. Armstrong got rid of the windage altogether, by means of a breech-loading gun. This was *cutting* the Gordian knot, but not untying it; and other obstacles then arose; the breech-loading principle naturally involved the necessity of a larger quantity of metal in the gun; in order to reduce the weight, it was, therefore, necessary to obtain a metal of superior strength; a difficulty which the indefatigable genius of Sir W. Armstrong enabled him to surmount; and he finally produced a gun, projectiles, and carriage, which formed, on the whole, a combination as remarkable for the beauty of its workmanship, as (compared with all that had gone before it) for the results which were obtained with it.

These results, however, are only obtained by the use of guns of the most elaborate workmanship, which can be produced only in small numbers and at an enormous cost; which require skilled labour and the most perfect construction; and of which the employment is objectionable in many other respects. The question therefore at issue is, whether all this is necessary; and whether the defect of windage cannot be sufficiently obviated by a more simple, inexpensive,

and effective combination. I maintain that this can be done; and the results obtained by myself, with the very inferior means (as to workmanship) which were at my disposal, are sufficient to justify this assertion.

The employment of the Armstrong gun is the first step to the general introduction of rifled cannon, as the breech-loading gun of former days was to the general employment of artillery; but it would be as great a fallacy now, as it would have been then, to suppose that no further improvement is possible. Should it unfortunately become a fixed idea that perfection is already attained, and should Sir W. Armstrong (who, in common with all who are interested in this attractive, but difficult and comprehensive subject, has yet much to learn) be inclined —which we will hope is not the case—to use his influence, as Engineer to the War Department, to put aside all experiments, except such as relate to his own invention; the country will, sooner or later, find to its cost, that, instead of having cause to rejoice at the success of his invention, it will have greater reason to deplore that it was ever brought so prominently forward. Other nations, too, might teach us our mistake in a manner not likely to be soon forgotten.

If a portion of the money expended by Government in building extensive factories for guns which, after all, are only experimental, were devoted previously to a proper course of experiments, it would be the greatest economy

in the end. It would then be discovered that those results, which are now considered so wonderful, are to be obtained by comparatively simple means.

I have to observe, that the projectiles which are represented in Plate 5, are merely *experimental*, and are described rather for the purpose of illustrating certain principles, than with the view of recommending them as being altogether the best adapted for practical use. A projectile of the description of the one represented in Plate 7 (*b*), is better adapted for horizontal firing, especially with guns of large calibre. The arrangement of its parts is similar to that which is shown in fig. 4, Plate 5, but a smaller quantity of lead is employed in the construction of the former, and the hinder part is made entirely of iron; the hindermost part, also, upon which the shell rests when placed in an upright position, is of a square or angular form.

I have not yet had an opportunity of firing these projectiles on a large scale; but, judging from the remarkably good results obtained with them when of a smaller size (1¼ lb.) they will probably be extremely efficient.

My object in firing the shells represented in plate 5, at Shoeburyness, was chiefly for the purpose of ascertaining certain effects in connection with the action of large charges of powder—of placing the centre of gravity in a very forward position, and other matters; rather than with the view of exhibiting any particular kind of projectile for use. A projectile, also, of similar form to the one shown in Plate 7, would have been too

heavy for the 32-pounder howitzer from which I fired the others; in fact, the gun was bored before I had perfected the arrangement of these shells; and to have fired them with a proper charge of powder, the bore should have been of smaller diameter.

It appeared so unlikely that the Committee would entertain the idea of adopting a compound projectile, that I made no further attempt to show what could really be accomplished with projectiles of this kind when fired from a suitable gun. It is almost superfluous to add, that each point in these projectiles has been made the subject of numerous experiments before the proper proportions were obtained; and that these proportions (which vary according to the calibre of the gun and the amount of windage) must be strictly observed. The figure (*b*) in Plate 7 will serve to give a general idea of the construction of these shells.

Although I have trespassed beyond the ordinary limits of a preface, I am yet induced to offer a remark respecting the expediency of coating ships of war (not floating batteries) with iron. It will be found, if it has not been so already, that ships cannot be made shot-proof against powerful rifled cannon, without depriving them of nearly all the most necessary qualities which a ship ought to possess; and it is to be borne in mind, that at a distance at which a properly constructed rifled projectile can strike a ship, it will have nearly, if not quite, the force of impact which it would have if the

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distance were much less; the loss of velocity in their case being very slight.

It appears, therefore,—taking a common sense view of the question,—that the best course to be adopted, under the circumstances, would be to construct the sides of ships of war in a manner which would allow the shot either (and I have seen such contrivances) to glance off, or, to pass as easily as possible *through* the ship; instead of creating a resistance to its passage which would not only be inffectual in preventing the entrance of the shot, but would tend greatly to increase its destructive effects.

In drawing the reader's attention to the foregoing remarks, I must also solicit his indulgence for extending them so far; my only excuse is the desire to assist, to the best of my power, in the development of that portion of the interesting and (especially to a great maritime power) important science of gunnery, which relates to rifled projectiles. Of this, at present so little is really known, that (I say it without hesitation) the majority of those who consider themselves tolerably well acquainted with the subject, if called upon to explain many of the circumstances attending the flight of these projectiles, would probably assign reasons for them, as remote from the truth, as would be those of an Australian native, if he were questioned as to the cause of the peculiar action of that extraordinary missile, the boomerang; which, with marvellous ingenuity, he can adapt to his purpose, but—lacking scientific knowledge—cannot properly explain.

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APPENDIX.

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ERRATA.

Page 16, line 17, for "feather" read "feathers."
„ 96, „ 15, for "8-inch gun" read "68-Pr. (8-in.) gun."
„ 96, „ 16, for "24" read "21."
„ 129, „ 2 from bottom, for "42" read "32."
„ 142, „ 9, for "equally good" read "equally as good."

RIFLED ORDNANCE.

INTRODUCTION.

The treatment and discussion of a subject purely military by one who is not in immediate connection with the Service, may seem to demand some apology. The theory of projectiles, however, presents to the scientific inquirer ample scope for investigation and experiment. To pronounce upon the most proper method of *applying* any fresh discovery affecting that theory, is solely for the consideration of competent military authorities; and wherever I have ventured to express any opinion on this point, I wish it to be understood, that it is under the correction of those who are better qualified than myself to judge of what may best accord with the practical requirements of the different Services. In other respects I have advanced nothing which has not previously been proved by experiment. The suggestions, therefore, which I have hazarded in the following pages, however imperfect, may not, I hope, be destitute of value.

As yet we have no satisfactory or conclusive authority to which we may refer on the subject of rifled cannon. The absence of all such authority may partly plead as an excuse for any imperfections in this slight attempt to supply the deficiency; and if the opinions expressed here do not meet with the entire concurrence of those who are best informed upon the subject, the publication of them may at least induce other and perhaps abler persons to assist in the development of this interesting but difficult question.

With the exception of those who are immediately interested in the matter, few persons are aware how much scientific research, as well as practical experience, is necessary for the acquirement of a knowledge of the laws respecting rifle projectiles, and for correctly ascertaining their capabilities. Indeed, it would be difficult to find a subject more comprehensive in its nature than that of rifled cannon.

My object has been to throw as much light upon the matter as possible. Whatever contributes to this is all the more important, as improvements in small arms render a corresponding improvement in cannon, if not absolutely necessary, at least extremely desirable. It is quite evident to all who have attentively studied the subject, that the same precision and relative efficiency which characterise the ordinary rifle can be as certainly obtained with cannon; still I must admit, after much investigation and many experiments, that the laws which govern the description of projectile to

which I purpose more particularly to direct attention, —that is to say, elongated shot, to be fired from rifled guns,—are, apparently not of a nature to admit of any of those very startling results, such as ranges of ten and even fourteen miles, which have been occasionally spoken of as possible.

The difficulties in the way of perfecting the construction of elongated shot and rifled guns are very much greater in the case of ordnance than in that of small arms. The want of a material sufficiently strong to resist and control the power inherent in a large charge of gunpowder, is also an impediment to such an increase of effect as would otherwise, perhaps, be attainable.

Very effective results may, nevertheless, be realised with rifled cannon, if properly constructed. The hope of extending the capabilities of this description of cannon induced me to turn my attention to the subject, and to make various experiments to test the soundness of the conclusions to which I had been led in the course of my investigations. Some of the results thus obtained are explained in the following pages, and may, perhaps, lead to useful improvements in gunnery. These results relate principally to the laws which should regulate the rifling of cannon for the purpose of enabling them to throw a heavier description of shot or shell. Hitherto the rifling of cannon seems to have been determined rather by accident or caprice than by any fixed and determinate rules; so that,

in fact, every rifled cannon which has been constructed can only be regarded as an "experiment."

One of the chief objects which I have in view is to show in what manner the principle of the rifle should be applied—from an accurate standard obtained in the first instance—to guns of all sizes. There would thus result to the Government at least this obvious advantage:—the cost of endless experiments would be spared, a cost which personal experience has convinced me must be enormous. If the present work, and the experiments upon which it is in a great measure founded, tend to further the acquisition of sufficient data for arriving at the object indicated above, it will be a source of gratification to know that the outlay has not been in vain.

ON RIFLED CANNON.

THAT great and striking advantages may be derived from the employment of rifled cannon has been long and fully acknowledged; yet is it within a comparatively recent period only that any serious intention of testing the applicability of this description of ordnance has been entertained. This is a remarkable fact. The cause must proceed either from ignorance of the capabilities of rifled cannon, or from insufficient data whereon to establish a fixed principle for their construction. Be this as it may, their trial has never yet been attended with sufficiently advantageous results to warrant their permanent adoption into our service. Had Robins lived to carry out his ideas upon the subject fully, it is probable that rifled cannon and long projectiles (the advantages of which that acute and scientific experimentalist was the first to appreciate and point out) would have been in use a hundred

years ago. It would be curious to speculate upon the effects which their introduction into warfare might have produced upon the events which have happened during that period.

The passage so frequently quoted from Robins's "Principles of Gunnery," where he predicts the great superiority which will be acquired by the nation first employing rifled barrels in warfare, evidently refers even more to cannon than to small arms. This will be seen by a perusal of the *whole* of the passage in question, which is as follows:—

"From the nature of these (*i.e.* rifled) pieces it is plain that they can only be made use of with leaden bullets, and consequently cannot be adapted to the adjusting of the motion of either shells or cannon bullets. However, from the same principle, whence these pieces derive their perfection, other artifices may be deduced for the regulating the flight of these more ponderous bodies. On some of these methods, which have occurred to me, I have already made several experiments; and there are others, which I have more lately considered, and which appear to me infallible. But there are many reasons why I should not now engage in a circumstantial discussion of this kind. I shall therefore close this paper with predicting, that whatever State shall thoroughly comprehend the nature and advantages of rifled-barrel pieces, and, having facilitated and completed their construction, shall introduce into their armies their general use with

a dexterity in the management of them, they will by this means acquire a superiority which will almost equal anything that has been done at any time by the particular excellence of any one kind of arms; and will perhaps fall but little short of the wonderful effects which histories relate to have been formerly produced by the first inventors of fire-arms."—*New Principles of Gunnery*, p. 341.

The use of rifled cannon not only prevents the deflection of shot, and insures greater accuracy of practice, but also, without increasing the weight of metal in the gun, admits the employment of heavier shot or shell, and obtains more extended ranges than is possible through the medium of any other kind of ordnance.

When the power and means of projection are limited, two methods suggest themselves for increasing the effect of projectiles: the one is by increasing their weight, and consequently causing a decrease in their velocity; the other, by diminishing their weight, and thus increasing their velocity. A very superficial knowledge of gunnery will lead to the conclusion that the best effect is produced by increasing the *weight* rather than the *velocity* (particularly when the latter has reached a certain magnitude) since the laws of the resistance of the air preclude the attainment of any great advantage by giving a shot more than a certain velocity.

As, however, it is not so much required in practice

to produce the greatest effect with a given shot, as with a *gun* of a given weight, the latter should first to be taken into consideration. Now, the production of great velocity requires heavy charges of powder, and greater thickness of metal in the gun, than is required for a proportionally increased weight of the shot; it will therefore be advantageous to give additional weight to the shot even at the expense of its velocity.

To illustrate this point, let us consider the results obtained by two different kinds of guns used in our service, both of about the same weight (17 cwt.); namely, a 32-pounder carronade, and a 9-pounder iron gun. The latter throws a 9 lb. shot nearly 1400 yards at an elevation of 4°, and the former, with rather a smaller charge of powder, throws a 32 lb. shot about 1000 yards at the same elevation (as may be seen by referring to the Tables of Ranges in any of the Treatises on Gunnery): so that with the same weight of metal, and a smaller charge of powder, the carronade throws a shot nearly four times the weight of that thrown by the 9-pounder, a distance equalling five-sevenths of that attained by the latter. Here we see that the greater comparative result is produced with the shot of the greater weight, and not with that possessing the greater velocity.

Now, if with a gun of the same weight as either of these, a 32 lb. shot could, with the above elevation, be sent to a greater distance than the 9 lb.

shot, it is undeniable that the means employed would be a sensible improvement upon existing arrangements. Still further would this be the case, if at the same time a greater degree of accuracy could be imparted to the shot.

This can be accomplished by the use of elongated shot—shot in which, while the *weight* is the same as that of the larger of the two shot above-mentioned, the *diameter* is that of the smaller, and therefore, the surface upon which the resistance of the air acts will be the same, or nearly so, as that of the smaller.

It is true that *at low elevations* the range of an elongated shot of nearly four times the weight of a spherical shot of the same diameter will not, with its necessarily reduced charge and initial velocity—supposing both shot to be fired from the same gun—be greater than that of the spherical shot, but at greater elevations, when the time of flight is longer, the superiority of the elongated shot is manifest. The weight of the latter being greater in proportion to the surface exposed to the resistance of the air, the velocity will suffer less diminution from that resistance; the curve of flight will therefore approximate more nearly to a parabola, and the range will be much greater than that of spherical shot.

The superior advantages to be obtained with a gun of 17 cwt. by the use of a shot or shell possessing a mean weight (20 lbs.) between the two shot mentioned above, but of reduced diameter and three times its

diameter in length, would, however, be very decided. With a charge af 2½ lbs. of powder, such a shot would attain a greater range, even when fired at the lower elevations, than either of those above-mentioned. The advantage becomes more remarkable as the elevation of the gun increases. Thus at an elevation of 10° the range of the projectile would be upwards of three thousand yards—or about half as far again that of the shot fired from the 9-pounder gun, and twice as far as that fired from the 32-pounder carronade.*

What the extreme range of such a shot would be when fired at the most advantageous elevation is difficult to determine. I have never witnessed the experiment, nor has it, I believe, ever been properly tried; but I should think it would be considerably more than double the range which it has at 10° of elevation.

For practical purposes this is, I imagine, about the greatest effect attainable with a gun of the above weight, on account of the recoil which would prevent the use of a much greater charge of powder, or a heavier projectile, as well as from a want of strength in the metal of the gun. In fact, with elongated shot very little is gained by increasing the charge of powder beyond one-seventh or one-eighth of their weight, for

* The result which I had here anticipated by reasoning on the ranges of the ranges of shot in use in the service, and of experimental shot made for myself, has since been verified in a remarkable manner by Armstrong's 18-pounder and other guns.

with larger charges their flight is not so certain. For this reason we can fire from a gun of a given weight a much heavier shot of an elongated, than of a spherical form.

By using guns combining lightness with strength—such as those of wrought iron or steel—greater proportionate results are of course attainable. Certain mechanical appliances, however, are necessary in their case to receive or deaden the recoil.

The weight of the gun as compared with that of the shot—of whatever metal the former may be constructed—must depend in a great measure on the character of the latter, *i.e.* whether it be of iron or of a compound of iron and lead. In the latter case the gun will require to be of greater strength, and therefore will be heavier as compared with the weight of the projectile. For in using compound shot there is little or no loss of power by windage, and therefore the action of the powder on the gun, and the consequent strain, is much greater than when iron shot are used.

The chief impediment to the use of elongated shot lies in the absolute necessity of giving them a rotary motion about their axes, in order to cause them to fly truly, and to keep their axes coincident with their lines of flight. Notwithstanding, therefore, the many objections which may be urged against the use of compound shot or shells, their employment becomes necessary when great precision is required; for it is impossible that long, homogeneous, and unexpanding shot can be made to describe truly a given line of

flight, on account of their not fitting the bore of the gun, so as to prevent them from shifting their position in the gun when on the point of quitting it. Their *range* also, for the same reason, bears no comparison with that of compound shot.

Elongated shells, constructed of iron only, possess certain advantages arising from the simplicity of their construction, but it is doubtful if they could be used, for any length of time, with brass, or even with wrought iron, guns. The friction which they produce is best resisted by cast iron guns. The friction of lead upon either of these metals may retard the shot in its passage through the gun as much, or even more, than that produced by solid iron shot, the friction of the former being distributed over the *whole surface* of the bore; still iron shells would cause much more damaging friction to the grooves, both on account of their hardness, and because they come in contact with *part* of the bore only. By having the projections on the shell lined with copper or other soft metal, the evil effects might be lessened; but under any circumstances the friction of these shot must always be more destructive to the gun than that of shot composed of lead and iron: indeed the effects produced upon the bore of a gun by the friction of the last-mentioned kind of shot are even less damaging than those of an ordinary spherical shot, especially when used with brass guns, from the friction being more uniformly distributed over the whole surface of the bore.

As the drawback to the use of compound shells is chiefly felt in storing and transporting them, it appears to me that this difficulty may be overcome by keeping them in cases: their superiority would fully compensate for the extra expense attending this.

ON THE TURN OF THE RIFLING.

In the construction of rifled cannon, too little importance seems to have been hitherto attached to the determination of the turn, or pitch of the grooves—a point upon which, in reality, failure or success almost entirely hinges. It is remarkable also that no one has attempted any discovery or definition of the laws by which that turn should be determined; for, however much opinions may differ on this head, it is tolerably clear that there must be some fixed laws, applicable to guns of every variety of calibre, by which this matter should be governed.*

Although the object I have in view is to explain the principle by which the grooves of guns of various sizes should, by means of a correct standard, have a proper turn assigned to each according to its calibre, rather

* Since the above was written, several small publications on Rifle Ordnance by foreign artillery officers have appeared, but as none of the theories there put forward are apparently the result of experiment, there is nothing to be learnt from them of the smallest practical use, although they are extremely ingenious, and interesting to read.

than to attempt to determine the proper amount of turn which should be given to the grooves of any particular kind of rifle, still it will be desirable to consider first, upon what circumstances the length of the turn to be given to the grooves of a rifle depends. It will be unnecessary for this purpose to enter upon a discussion of all the laws relating to projectiles: those only will be noticed which bear immediately on the subject at present before us.

The question which suggests itself as the first for our consideration is this:—What is the cause which renders a projectile of an elongated form more efficient when it has imparted to it a rotary motion about an axis situated in the direction of its flight?

It will be admitted on all hands that the correct answer to this question, is, that such a rotation enables the projectile to resist the deflecting power of the air better. Experiment further shows that in order to obtain the best effect with a particular shot, a *certain* velocity of rotation should be imparted to it, which will not be the same for different kinds of bullets.

Opinions have differed as to whether the rotary motion of the shot arises solely from its constrained passage along the grooves formed in the barrel of the gun; or whether the grooves simply impart a first rotary impulse to the shot, the rotation being continued during the shot's flight by the action of the air against the projections upon the surface of the shot. Although many persons possessing experience in such

matters, (amongst others Colonel Beaufoy, the author of "Scloppetaria,") have asserted the latter to be the case, all the experiments made with elongated shot give very decided proofs that the former is the correct view,—viz., —that the rotary motion given to the shot is caused *solely* by the twist which it receives in passing through the barrel of the gun; and that the pressure of the air, so far from promoting or assisting it in any way, acts continually as a check upon it, in proportion both to the length of the shot and the velocity with which it is fired.

The idea that the air promotes the rotary motion which a rifled shot receives is partially founded upon a certain supposed analogy between a shot and an arrow, and consistently with this idea attempts have been made at various times to procure for the former a rotary motion by means of wings or grooves similar to the feather of an arrow. The two are, however, by no means analogous. An arrow is a shaft of wood pointed with iron, which has very little tendency to turn over in its flight, for two reasons; firstly, because the resistance of the air to such a motion is very great owing to the length of the shaft and its comparatively small density; secondly, because the direction of the original impulse passes almost exactly through the centre of gravity of the arrow, which cannot be secured in the case of iron shot. Supposing also an arrow to begin to turn over in its flight, this motion would be checked by the resistance of the air in consequence of the forward position of the centre of gravity.

The feathers on an arrow are usually placed in a straight, and not in an oblique direction, (as some imagine,) upon the hinder part of the shaft. Placed obliquely they diminish the speed and range of the arrow. Both the action and effect of these parts of an arrow have been greatly misunderstood. In consequence of the *breadth* of the surface presented by the feathers, any tendency of the arrow to rotate about its shorter axis is checked, and the flight rendered steady. Three feathers will thus keep an arrow more steady than two, as with three, in whichever direction the shaft moves the flat surface of the feathers will encounter the resistance of the air. The feathers also materially contribute to the arrow following the curve of flight, so as to be a tangent to it at every point.

But with long shot the case is altogether different; these require an equivalent to the long, well balanced and feathered shaft, with which the arrow is provided, in order to counteract the tendency they would have to rotate about their smaller axis, or turn over. This can only be obtained by imparting to the projectile a rapid rotary motion about an axis situated in the direction of its flight.

It is true, that by constructing a compound shot of iron and some light material, in such a manner that its centre of gravity may be thrown forward considerably, and by supplying it with projections, or some substitute corresponding to the feathers in an arrow, it may be

made to approximate more nearly to the condition of the latter; and in such a case, a certain analogy may appear to exist between them; but the shot, from its deficiency in length, and its more uniform density (unlike the arrow) possesses no means of checking any tendency to turn over or rotate about its shorter axis, and consequently requires a large rotary velocity to counteract it.

I made a few experiments with long shot, of which the front part was composed of iron, and the hinder of wood and other light material, firing them from a smooth-bored gun; the resistance of the air prevented these shots turning completely over, but they obtained only a very low velocity, and there was an obvious oscillating of the "tail" of the shot during its flight. And it is clear that if the projections on the shot are sufficient to counteract its tendency to turn over, they must materially reduce its velocity, and thus impair its effect. In fact, however ingenious many of these and other inventions connected with projectiles may be, unless the full power of ordinary shot, either with regard to velocity or range, can be obtained with them, they are practically useless.

Elongated shot, when fired from a *rifle*, have the defects of the shot above-mentioned remedied by having a rotary motion imparted to them in the first instance. This gives them a proper degree of stability, and allows of their being fired with a sufficient velocity to enable them to be used with great effect; and even

if fired with a high velocity, the velocity of their rotation, being in proportion to that given to their flight, is sufficient to secure steadiness of motion. If, however, they are fired with too great a velocity, *they* also will have an irregular flight, but not attributable to the same cause which produces unsteadiness of flight in an arrow.

There were formerly more grounds for the opinion that the rotation of the shot was caused by the action of the air upon it during its flight, when rifles with deep cut grooves were used; but to suppose it possible that such an effect can be produced by the action of the air upon such a bullet as, for instance, that fired from the Enfield rifle, upon which the projections caused by the grooves are scarcely perceptible, seems altogether absurd. If the air *promoted* the rotary motion in the shot, its effect in that way would be more apparent upon elongated than upon spherical shot of the same diameter.

On the other hand, if the pressure of the air retards the rotation, this effect, too, will be more perceptible with long shot than with round; and as experiment clearly shows that the rotation of long shot is more rapidly checked than that of round ones, by the action of the air, the necessary inference is that the action of the air checks the rotation, instead of assisting it.

Since it is principally, if not entirely, from the resistance of the air that the necessity for rifling shot arises,

the proper degree of rotation to be given to a shot will depend upon its form and weight, or rather density, and also on its size, all of which circumstances greatly modify the resistance of the air and its effect on the shot.

And again, since the rotary motion is imparted to the shot by means of the grooves in the barrel of the gun, part of the energy of the charge will be expended in overcoming the resistance of the grooves supposed smooth, and a still further portion in overcoming the friction caused in practice by their roughness.

In the present chapter I propose to apply these principles, together with the results of experiments presently to be stated, in a general way to the subject of the proper turn for rifled guns; reserving for a future chapter, the statement and proof of an approximate rule by which the variation of the turn with the calibre of the gun may be determined.

The question as to the best turn to be given to the grooves in small arms, where the ordinary bullet of about an ounce weight is used, appears to be settled in favour of a whole turn in about thirty inches;* but

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* The length of turn, whole turn, or complete spiral, are synonymous terms, signifying the length of barrel through which the shot would be compelled to move in making one complete revolution. The length of turn, however, is considered apart from the length of the bore of the gun, which may be of such a length as only to admit of the grooves describing a portion—such as a half, or a

touching that which is best for elongated shot, opinions somewhat differ.

It will be found, however, upon examination, that it is chiefly the difference in the weight and shape of the shot which causes one rifle to shoot better with a less, and another with a greater turn. If the proper length of turn were fixed by a correct standard, according to the weight and shape of the bullets used, the existing disparity between the turns of different rifles would be accounted for, since the same laws must equally govern both.

The shape and weight of the shot are undoubtedly the first objects for consideration in this matter, as having a direct influence upon the length of the turn. For when a shot of fixed weight is to be fired with a given charge, the only way of increasing the velocity of rotation is by the employment of a greater turn; therefore, as a general rule, whatever tends to check or render inefficient that velocity, such as the form of the shot offering great resistance to the air, the want in the shot of a certain density, or any other cause, will necessitate the use of a greater turn proportional

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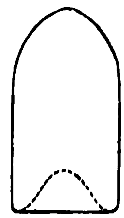
quarter of a turn; for instance, the bore of the gun may be only two feet in length while the length of the turn is four feet—in which case the gun would be said to have half a turn. In general, in speaking of the turn of the grooves, we call that a "great turn" which gives a great rotary velocity to the shot, or will cause it to make a complete turn in a short space; a small turn is productive of an opposite result.

to the additional velocity of rotation required to be given.

In the absence of sufficient data concerning the effect produced by different kinds of shot with rifled guns of large calibre, let us observe the different effects of the variously shaped bullets now in use upon the turn in small arms. The most celebrated are Pritchett's, used with the Enfield, and superseding the Minié, and many others; Major Jacob's; and I may perhaps mention those used for Colt's pistols. I have taken these as examples of the opposite means employed (namely the great and small turn) for producing the greatest effect,

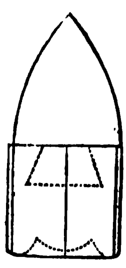
Fig. 1.



Pritchett's.

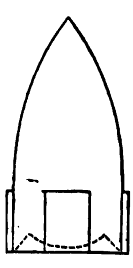
The Pritchett bullet (Fig. 1), is about two diameters in length, and of a cylindro-conoidal form. It is homogeneous, and has its centre of gravity situated near its centre, very slightly if at all forward; it is used with a rifle (the Enfield), having a turn in 6 ft. 6 in., and a bore ·577 in. in diameter.

Fig. 2.



Jacob's.

Fig. 3.

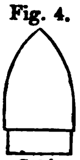


Jacob's.

Major Jacob's bullets (Figs. 2 and 3), are not quite so heavy, and more nearly approach a conical form. They have four projections, which fit the grooves, and are necessary, I believe, to prevent the bullet stripping, on account of the great turn used with it. The fore part of the bullet is of zinc or steel, and its centre of gravity is in

the hind part; it is fired from a rifle having a turn in 24 in. (or in some cases 36 in.) only, the diameter of the bore being the same as in the preceding instance.

Fig. 4.



Colt's.

The bullet used with Colt's pistols (Fig. 4), approaches the form of Major Jacob's, but has no projections or steel point. Nearly the same turn is used for the two, and with Colt's a heavier charge of powder than is commonly used for a pistol is employed.

Here then, at first sight, appears an unaccountable disparity in the turn employed, the length of turn in one case being 6 ft., in the other only 2 ft.; but if attention be paid to the difference of form in the bullets, it will be perceived that there are three or four very sufficient reasons why that of Major Jacob should require a greater turn than Pritchett's.

In the first place, on account of its zinc or steel point, Major Jacob's has somewhat less density than Pritchett's, and therefore, the retarding force of the air diminishes its velocity more rapidly. Secondly:—Its form being much more conical, offers a greater surface in proportion to its weight to the direct resistance of the air in its rotary movement. Thirdly:—The position of its centre of gravity (being in the hinder part) requires a greater velocity of rotation to be given to it, in order to preserve its proper direction and overcome its inclination to turn over, as its want of stability increases

with the distance that its centre of gravity is behind the centre of its figure. Fourthly:—The projections formed upon it offer greater resistance to the air in the act of rotation than in the other bullet.

Each of these circumstances unquestionably affects the flight of the shot, and therefore exerts more or less influence upon the turn. Notwithstanding this fact, we frequently find persons advocating the employment, some of a greater and others of a less turn, either as their fancy seems to dictate, or from considerations altogether unconnected with the form of the bullet.

No one, I think, will deny that of two bullets, the one which requires the least angular velocity consistently with the attainment of certain results is that which presents the greatest advantages. A large angular velocity requires a sharp turn of the grooves, in consequence of which the velocity of the shot is diminished materially, both in consequence of the friction properly so called against the grooves, and the resistance of the grooves, whereby the shot is constrained to move in a spiral, instead of directly forward. The strain upon the gun, the recoil, and the tendency of the projectile to fracture or to *strip*, are also thereby considerably increased; hence, any advantages which might result from great angular velocity, imparted by means of a grooved bore, are so nullified by the increase of friction that in some cases more is gained, in a practical point of view,

by lessening the friction, especially with guns used for horizontal fire, than is lost by diminishing the angular velocity of the projectile.

Simple representations as to the range and accuracy of certain bullets, unaccompanied by a complete statement of all the circumstances attending their trial prove little or nothing. It has been stated that Major Jacob's bullets will strike an object with more force, and at a much greater distance, than has been attained by Pritchett's, but I think this is questionable; for if the Pritchett bullet has sufficient turn to keep it straight during its whole flight, it must have a greater range than Major Jacob's, in consequence of its superior density, and also because the angle of the turn which it requires is less, and its form offers less resistance to the air. It is not improbable, however, that the turn of 6 ft. 6 in. is somewhat too slight for the Pritchett bullet, when fired at more than a certain elevation, and therefore that the great turn used by Colonel Jacob, and the consequent great precision of fire obtained with it at long ranges, may, perhaps, cause his to have actually a greater range than the bullet used for the Enfield musket; for we find that when a great velocity of translation is given to a shot without also imparting to it a sufficient turn, the rotation, diminishing with the time of flight, becomes at last insufficient to preserve the coincidence between the axis of the shot and the line of flight, and therefore accuracy of fire at long distances is rendered impossible. This is a result

which must, of course, be avoided, since with rifled guns great accuracy is the first thing to be secured. Extent of range, which is the next important point, will also be diminished unless the turn be sufficient to maintain the flight steady.

This may apply in some measure to the Enfield rifle, for the difference in the form alone of the balls would hardly require so great a difference in the turns employed in this and in Jacob's.*

The steel point in Major Jacob's bullet may possess some advantages, where it is a question of firing leaden bullets of a particular form with great velocities (see his *Rifle Practice*, p. 23—26); but in other respects

* As all troops of the line are, or probably will be, armed with the Enfield musket, it would, perhaps, be advantageous to furnish the rifle brigade with a rifle having a shorter and stouter barrel, to carry a bullet of the same diameter, but a trifle heavier, and to be charged with a rather heavier charge of powder; the friction would be reduced, and a greater range might be obtained. If the turn were found insufficient to keep the bullet true during its longer serviceable range, the turn might be increased to the extent required. By this means the effective range of small arms might be carried to its utmost limit. I would suggest that the barrel be of the same weight as the present, but 30 in. only in length, having a turn in 60 in., or one even greater, and charged with 2¾ drachms of powder, and a bullet weighing 20 drachms. Such a rifle would be a much handier weapon than the present, and would secure greater precision of fire at long distances, and in the hands of riflemen would ensure precisely those advantages in respect to range, &c., the realization of which is so essential. It is necessary

the advantages appear to be considerably in favour of the form of the Pritchett bullet, as more conducive to great range, and also as requiring a less turn to keep it true,—two very important considerations.

To the bullets here cited as examples of the manner in which the *form* of the projectile influences the turn, may now be added that of Mr. Whitworth, the form of which is shown in Fig. 1, Plate 2. This bullet, which is of the same weight as the one used with the Enfield rifle, but of smaller diameter, and three diameters long, has a range of 1400 yards when fired at an elevation of 5°. The turn which is found most suitable for it is one of 20 in. in length only. From the hexagonal form of Mr. Whitworth's bullet, as well as from its great length, a great turn is necessary, as the resistance of the air to the rotation of this bullet is unusually great. The superior range and accuracy of this bullet is due to its small diameter and undiminished weight, and to its having a rotary velocity in proportion to its sustained flight.

For shot of great length a great turn is absolutely necessary. I made frequent experiments with shot, ranging in length from one and a half to between

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to observe that a quicker turn requires a quicker expansion of the bullet, to obviate the chance of stripping. Various methods may be employed for obtaining this; the bullet shown in Fig. 3, Appendix (A), is well adapted for this purpose. A rapid expansion also prevents the barrel fouling, and the loss of force by windage, since the gas is not permitted to escape so freely.

four and five diameters, in order to ascertain certain points in connection with this circumstance, and I invariably found that the greater the length of the shot the greater was the turn that was required for the grooves.

This result, which was certainly not anticipated, may probably be explained as follows. When a long shot is passing through the air it is acted upon in two different ways by the air. There is first the resistance of the air, strictly so called, on the fore part of the shot, which tends to diminish the velocity of the shot's onward flight, but will have little if any effect on its velocity of rotation. Secondly, there is the lateral pressure or friction of the air on the *length* of the shot, which will diminish and at last destroy entirely the rotation of the shot, but will have comparatively little effect on its (onward) velocity of translation. This being admitted, we will take for example the case of two shot of the same diameter, of which one is twice the length of the other. Supposing them fired with the same initial velocity and the same rotation, it will be seen that the velocity of translation will be much less affected by the resistance of the air in the case of the long shot than in that of the shorter; while the velocity of rotation will be equally diminished in both, so that in the longer shot the velocity of rotation will be more rapidly diminished in proportion to that of translation, and will sooner be reduced below the amount necessary to keep the flight of the shot steady. In order, therefore, to give the

longer shot the same accuracy in its flight, it would be necessary to give it in the first instance a much greater velocity of rotation, which would require a greater turn in the grooves, and, as a consequence, involve a diminution of the range and the danger of the shot stripping. It must be noticed that any projections on the shot caused by its passage through the grooves will very much increase the friction of the air on the longitudinal surface of the shot, and accelerate the diminution of the rotary velocity.

For another reason also, projectiles of great length require an increased velocity of rotation. In my experiments I found that shot of great length turned completely over on leaving the muzzle of the gun although the turn was sufficient to keep a shot of less length perfectly straight. This fact I find is fully corroborated by Mr. Whitworth in his paper on rifled fire-arms; (*On Mechanical Subjects*, page 77); in which he states that the length of turn (6 ft. 6 in.) used with the Enfield rifle, and which is found to give the bullet the rotary velocity necessary to keep it straight, was so inadequate for a bullet nearly double the length of the ordinary bullet, that the former turned over within a distance of 6 ft. from the muzzle of the gun.

From this it must be inferred that the *stability* of a long projectile of a given diameter is diminished by an increase in its length; and therefore, that it will require a greater rotary velocity than one of shorter length to keep it straight. This is perfectly in

accordance with the mechanical laws, for the greater the length of a body in proportion to its diameter, the more unstable will be its equilibrium; that is to say, a smaller amount of force will be necessary to disturb it. Thus, in spinning two tops of the same diameter, one of which is three times the length of the other, the longer will require the greater rotary velocity to preserve its equilibrium; but, the equilibrium once disturbed, the movement about its smaller axis will be less rapid than the movement made by the smaller under similar circumstances.

To obtain the best results, therefore, with the rifle projectiles, it appears, for various reasons, that their length must be exceedingly limited.

The greatest length which can be used with effect appears, from experiments which I have made, to be about three times the diameter of the shot—at least in the case of shot similar to the examples shown in Plate 5. When the shot were longer than this, I found the range that could be obtained with them was diminished, on account of the great turn and the low initial velocity it was necessary to give them. On the other hand, when their length was less than this, the range was also diminished, in consequence of the smaller weight of the shot, and the greater comparative effect of the resistance of the air; on the whole, therefore, one of three diameters in length has sufficient advantage over one of two diameters to compensate, in most cases, for the greater turn required for it. For small arms, how-

ever, the circumstances of its length and the greater turn may render it practically less fit for service than a bullet of the size and form of that now in use, especially as the advantages possessed by longer shot are not so apparent at the lower elevations.

The turn of the grooves, whether for rifled ordnance or for small arms, will depend, not only upon the description of projectiles employed, but also upon the nature of the service for which such arms are required, being greater or less according as the gun is intended to be used with a high or low elevation.

It is clearly established by experiment, that a velocity of rotation which is sufficient to keep the flight of a shot true for a certain range, may be quite insufficient for the purpose when the elevation is increased. This probably arises from the circumstance that the friction of the air on the shot continually diminishes its velocity of rotation, so that when the time of flight is great, the velocity of rotation may be reduced to an amount quite insufficient to secure steadiness of flight. When therefore the elevation of a gun is great, and therefore the time of flight increased, a greater turn will be required for the grooves, in order to secure sufficient velocity of rotation throughout the flight of the shot.

With the military rifle, forty years ago, one turn in 10 feet only, or a quarter turn in a barrel 30 inches long, and a very heavy charge of powder were used; and it was found upon trial to shoot as accurately at 100 yards, as others with four times the turn; but the

latter were found so immeasurably superior to it at all distances beyond this, that the turn was afterwards considerably increased. ("*Scloppetaria*," p. 82—86.)

I will now proceed briefly to consider the question as to whether a different *velocity of projection* should have any influence on the turn, and I think that if we attentively examine the causes which exist for giving to shot a rotary velocity, it will be found that the rotary movement being obtained by means of a grooved bore, the velocity of projection will not, necessarily, affect the length of the turn so much as we might at first be led to imagine.

For the velocity of rotation is always in exact proportion to the velocity of projection, and although the resistance of the air increases in a higher ratio than the velocity, yet there are strong reasons for concluding, that for practical purposes, almost, if not quite as great a turn is required for a low as for a high velocity of projection.

A certain want of homogeneity and concentricity exists in a greater or less degree in all long projectiles used for cannon. These give the shot a tendency to rotate about an axis not situated directly in its centre, and this tendency is greater when the rotary velocity is small than when it is great. Again, when the velocity of projection is small, the flight of the shot becomes more incurvated, and high elevations usually accompany low velocities (as with mortars), in which case the time of flight is also extended, all of which circumstances conduce to the employment of a great turn.

From this we may infer that comparatively as great a velocity of rotation, or as great a turn, is necessary for most rifle projectiles in cases when they are likely to be fired with low velocities, as when they would be fired with high; for even with the smallest velocity of translation, when the resistance of the air would be reduced to a minimum, a certain rotary velocity is necessary, in order to give a proper stability to the axis about which the projectile turns, and to ensure the perfect steadiness of its flight; for the same reason that a humming-top, which has no progressive motion, requires a certain velocity of rotation to be given to it, to enable it to maintain its equilibrium when placed in an upright position.

I am not aware that any experiments have been made for ascertaining the velocities of rifled projectiles with the ballistic pendulum, and therefore I am unable to state precisely the greatest velocity which can be given to elongated shot, without prejudice to their rotary movement, or to their steadiness of flight; but, judging by the ordinary rules for ascertaining the velocities of shot, it would be about 1,200 or 1,300 feet in a second, varying according to the length and make of the shot.

A moderate velocity only could be given to rifle projectiles fired at great elevations, as, for example, from mortars, owing to the great turn which is necessary to enable them to maintain their accuracy of flight to the full extent of their range; for the velocity of the pro-

jectile has its least value soon after passing the vertex of the curve of flight, and during the descent of the shot, its velocity will continually increase, whilst its rotary movement will continually diminish.

For horizontal firing, on the other hand, great range being an object, it would be necessary to employ the highest possible projectile velocities. With guns of heavy calibre, this would be furthered by the use of a comparatively shorter projectile, and a smaller turn; the *weight* of the projectile being maintained by increasing the diameter of the bore.

With guns of large calibre, the greatest range at low elevations may be obtained in the manner above-mentioned; but, if fired at the higher elevations, the flight of the projectile will not by any means be so accurate, nor will its range at these elevations exceed that of a longer shell fired with a greater turn and smaller velocity.

This proceeds both from the better sustained velocity of the longer projectile, and from the fact, that when the turn is insufficient to keep a projectile steady throughout its whole flight, the surface exposed to the direct resistance of the air becomes greater in proportion as its flight becomes unsteady, and this not only causes deflection, but also a diminution of velocity.*

* From the circumstance that the actual range and force of impact of shots which have a rapid rotary motion imparted to them,

Thus we obtain widely different results, according as we give on the one hand, a considerable turn and a low velocity to a shot, or, on the other, a slight turn and a greater velocity. If, therefore, it were found expedient to employ both these methods, care should be taken that neither be exaggerated, as in the one case the range itself, and in the other the range at which a proper degree of accuracy could be attained, would be too much diminished for practical purposes.

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is frequently greater, from their steady flight, than that of others which have only a slight rotary motion, has probably arisen the absurd idea that a violent rotary motion causes the shot to penetrate, or *bore* its way into hard substances.

ON THE INFLUENCE WHICH THE *SIZE* OF THE PROJECTILE HAS UPON THE TURN OF THE GROOVES IN RIFLED GUNS.

THIS question, if not the *first*, is one of the earliest to which attention should be directed; for, certainly, no experiments connected with the mechanical part of the application of the principle of the rifle to cannon, can possibly be productive of satisfactory results, until the effect actually produced on the flight of the projectile by an alteration in its *size*, be first clearly ascertained.

The difficulty of estimating the exact amount of angular velocity required for shot of different forms, and the effect of the action of the air upon them, precludes the possibility of any determinate length of turn being assigned beforehand by theory for any particular kind of shot;—this can only be learnt by experiment. For shot of different diameters, but of similar forms, a fixed scale may, however, be made; as in their case we have to deal with a difference in the *quantity* of pressure only, which is always in a certain

proportion to their diameters with every kind of shot.

As, therefore, some modification of the turn will be found necessary in all cases where the shot materially differ in form and weight, it must be supposed, before entering into any explanation respecting the relative turn to be employed for guns of different calibres, that the description of projectile and the turn most suitable for it when fired from a gun of a certain calibre, have first been decided upon. Assuming these to be already ascertained, I propose to inquire what turn should be given to a bullet similar in form but of larger dimensions. Lest, however, the propositions which I am about to advance should be thought to savour too much of theory, I may observe, that all the arguments made use of have been suggested, and all the conclusions confirmed, by a long course of practical experiments.

Hitherto, in rifling cannon, two extreme methods appear to have found most favour: one consisting in giving the grooves a length of turn of about the same number of calibres as in a rifle carrying an ounce ball; the other in giving them a turn of scarcely greater length than that used for small arms; no satisfactory reason, that I have ever heard of, being assigned for either system. The advocates of both these methods appear to overlook the fact that the circumstances attending the projection of the shot, the resistance of the air, time of flight, range, velocity, &c., will all be in a different ratio to each other with a gun of large

calibre, to what they are in one of small calibre, and must therefore be considered.

Others, again, are of opinion that the length of the turn should depend in some measure upon the length of the *gun;* that a quicker turn should be used with a short, than with a long gun. This is clearly a fallacy, for if the shot would acquire a sufficient rotary velocity when fired from a long gun with a less turn, it would not require a greater when fired from a short gun. The length of turn must depend alone upon the rotary velocity required for the shot, and the comparative turn for shot which differ in size only, will depend entirely upon the comparative influence of the air upon them.

All who have any knowledge of the science of gunnery are aware that the velocity of projection being the same, large shot range further than small ones, *cœteris paribus.*

This circumstance is noticed and explained by Robins in his "Tracts on Gunnery." At page 256, he observes, that—"A 24-pounder loaded in the customary manner and elevated to 8°, ranges its bullet at a medium to about a mile and a half, whereas a 3-pounder, which is half the diameter, will, in the same circumstances, range but little more than a mile; and the same holds true in the other angles of elevation, though indeed, the more considerable the angle of elevation, the greater is the inequality of the ranges. Now this diversity in the range of unequal bullets cannot be imputed to any difference in their

velocities, since, when loaded alike, they are all of them discharged with nearly the same celerity, but it is to be altogether ascribed to the different resistances they undergo during their flight through the air: for, though a shot eight times the weight of another has four times the resistance, yet, as it has eight times the solidity, the whole retarding force which arises from the comparison of the resistance with the matter to be moved will be but half as much in the larger shot; and thus it will always happen (whatever be the size of the shot) that the retarding force of the air on the lesser shot will be greater than the retarding force on the larger, in the same proportion as the diameter of the larger shot is greater than the diameter of the lesser."

We have therefore to consider, in rifling guns of large calibre, in what manner the relative increase in the weight and size of shot will affect the turn, this being absolutely the only point on which those projectiles of the same form and density will differ.

If the resistance of the air were proportional to the weight of the shot, it is clear that shot of similar form, whatever their size, would require the *same* degree of angular velocity to insure their stability.

A long shot fired in a vacuum would in general require no rotation at all, for although it would always turn over in its flight, still, there being no resistance to its flight, this would not be attended with an injurious effect on its velocity or direction;—the prac-

tice would be equally accurate whether the gun were rifled or not, and in the latter case there would be a greater velocity. If it were required under the same circumstances to use a long projectile as a percussion shell, it would then become necessary to rifle the gun in order that the projectile might always present the same end foremost; but a small velocity of rotation would probably suffice for this purpose.

A round shot fired in a vacuum would require no rotary velocity whatever, for it is only the resistance of the air, acting in an oblique direction, in consequence of the rotation of such shot about an uncertain axis, which causes the deflection always noticed in practice.

The resistance of the air being, therefore, the only cause which renders the rifling necessary, whatever tends to lessen this resistance, or its effect on the shot, will allow a corresponding diminution to be made in the velocity of the shot's rotation. If the density or weight of a shot be increased, without any increase in its surface, the retarding force of the air will be lessened in proportion; but if an increase, corresponding to its increase of weight, be made in its surface, the effects will neutralise each other.

In the preceding extract from Robins's "Principles of Gunnery," the comparative difference in the retarding effect of the air upon shot of different sizes, is noticed in general terms only, but for the present purpose it will be necessary to examine the subject a little more closely.

In estimating the amount of resistance offered by the air to shot of different diameters, it is a common error to take into account the action of the air upon the projectiles at the first instant of their motion only; or, in other words, it is generally believed, and often stated, even by able writers, that a shot double the diameter of another, and therefore having half the extent of surface as compared with the weight, will only suffer half the amount of resistance from the air. Were this the case, it would be true that the angular velocity necessary for large shot might be diminished in proportion to their diameters.

In order to show the error of this opinion, let us suppose two shots of similar form and the same density, but the diameter of one double that of the other, fired with the same initial velocity. It is then perfectly true that at the first instant of projection the resistance of the air on the larger shot is four times that on the smaller, and since the weight of the larger is eight times that of the smaller, the larger will be retarded only *half* as much as the smaller. In consequence of this, its velocity at every other instant of its flight will be larger than that of the smaller, and the resistance of the air will therefore be *more* than four times as large, and its retarding effect *more* than half that on the smaller; or, in other words, the total retarding force of the air will be more than half what it is on the smaller—so that it will clearly be prevented acquiring an excess of range over that of the smaller,

in proportion to the difference between the weights and surfaces.

Instead of the proportion thus shown to be erroneous, theory and practice both point to the conclusion that the total effect of the retarding force of the air upon shot of different sizes, but of the same form and density, during the whole of their flight, varies very nearly as the *square roots of their diameters.* This I will now proceed to establish.

In the first place, we find (from a proposition demonstrated by Professor Euler, and which may be regarded as one of the few *certain* rules we possess with regard to the flight of projectiles,) that "*bodies of the same density and form, projected with the same elevations, and with velocities as the square root of their diameters, will describe similar curves, as the resistance will be in the ratio of their quantities of motion,*" a fact which shows that the actual amount of the resistance of the air upon shot of different sizes, is as the square root of their diameters. This is comparatively a simple deduction from the law—that the resistance of the air varies as the square of the velocity.

As the resistance of the air upon shot of different diameters, projected with velocities as the square root of their diameters, is, relatively, the *same*, it follows, that the *rotary* velocity required for each must also be the same; and that, consequently, as the velocity of large shot exceeds that of small in proportion to the

square roots of their diameters, the length of the turn of the grooves for the larger shot (in order to give each the same angular velocity) must be increased in the same proportion.* If, then, the turn be sufficient in one instance, by following this method, *the angular velocity* (whatever the velocity of translation), *will always be in the same ratio to their comparative resistances with shot of all sizes.*

Another method of computing the comparative effect of the air upon shot of different sizes, or (if I may so express myself) the power acquired by shot of increased weight of overcoming the resistance of the air, is to compare their *terminal velocities.*

A shot descending through the air solely under the influence of gravitation, will gradually increase in velocity until it meets with a resistance from the atmosphere equal to its own weight; the impelling force and resistance being then equal, it will continue to descend with the same uniform velocity, which, of course, will differ according to the weight and diameter of the shot, but which is in every instance called its "terminal velocity."

It has been computed that the terminal velocities of shot are proportional to the square roots of their diameters nearly; thus the terminal velocity of a 3-lb.

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* In fact, if ω is the angular velocity, and v the linear velocity of the shot, and l the length of the turn of the grooves, $\omega = \frac{2\pi v}{l}$ and therefore $l \propto v$ when ω is constant.

is proportion to the difference between [illegible] and surfaces.

Instead of the proportion thus shown [illegible] ences, theory and practice both point to the [illegible] that the total effect of the retarding force of [illegible] upon shot of different sizes, but of the same form [illegible] density, during the whole of their flight, varies [illegible] nearly as the *square roots of their diameters*. Th[illegible] will now proceed to establish.

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shot is about 290 feet a second, and that of a 24-lb. shot (which has twice its diameter) about 420 ft. (Hutton, Tract 37, problem x.); so that if these two shot in falling through the air had each attained its terminal velocity, the smaller would continue to descend with a velocity of about one-third less than that of the larger, the retarding force of the air being, relatively, really so much greater upon it.* It should be noticed, however, that the shot in falling would never actually acquire this terminal velocity, but one which would approximate closely to it.

It is observable in practice, that the ranges of variously sized round shot, when fired at the highest effective elevations, will, as a general rule, be found proportionate to the terminal velocity of each shot, the velocity of projection being the same.

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* When shot, similar in form, but of different sizes, are fired with the same initial velocities, the larger will always maintain a superior degree of velocity, regulated by their greater terminal velocities, so that it is not their weight alone which causes their effect to be greater, but their less diminished velocity adds considerably to their otherwise increased force of impact and general effect. When, therefore, the weight of the gun is limited, and the circumstances under which it can be used conveniently admit of the employment of greater elevations, the advantages—especially with the heavier kinds of ordnance—are enormously in favour of a heavy, over a light, projectile, although the latter be used with a greater initial velocity; as (except at short distances) a greater proportionate effect can be produced with a larger shot, and a lower initial velocity.

Supposing long projectiles of the same form, but of different sizes, always to move point foremost, their comparative terminal velocities will bear the same ratio to each other as those of round shot, provided the flight of each be equally steady; it is for this reason that the perfectly steady flight of elongated shot is of so much importance, for a want of it not only causes more or less deflection in the projectile, but will considerably diminish its terminal velocity, and its range.

The following is a Table of the different terminal velocities of round shot, of various sizes, taken from Hutton's Tables (Tract 37, problem x.); to which I have added their respective ranges, when fired with 5° of elevation, and with charges equal to one-third of their weight, that is to say, with initial velocities of about 1,800 feet a second.

Weight in lbs.	Diameter in inches.	Terminal Vel. in feet.	Range at 5° in yards.
1	1·928	247	1,100
2	2·423	277	1,210
3	2·773	297	1,300
4	3·053	311	1,400
6	3·494	333	1,520
9	4·000	356	1,650
12	4·403	374	1,700
18	5·04	400	1,780
24	5·546	419	1,850
32	6·106	440	1,950
42	6·684	461	2,050
68	7·95	530	2,240

The terminal velocities of spherical shells are to those of spherical solid shot of the same diameter, in the ratio of 1 to $\sqrt{1\cdot 5}$.

The terminal velocity of a long shot, as compared with that of a round shot of the same diameter, will be about as the square root of the weight; and the additional range acquired by the long shot should be (within certain limits) in about the same proportion.

An Enfield bullet, which, from its form and density, has very nearly the same terminal velocity as a 1-lb. iron round shot, has also a similar range when fired with the above elevation. From which it appears that, in the case of the bullet, the advantage produced by the absence of windage, fully counterbalances the disadvantages occasioned by friction, and a smaller charge of powder.

In order to illustrato the method here proposed for finding the proper length of turn for guns of various calibres, we will suppose that it is required to find the proper length of turn for a gun with a bore 4·2 inches in diameter, it having been previously ascertained that a turn in 64 inches is that most suitable for a gun having a bore of 1·2 inches in diameter; the shot used in each case being of similar construction.

It has been shown that the length of the turn should be increased in proportion to the square root of the calibre, so that the rule for finding the proper turn may be expressed at length in words, as follows:—divide the larger diameter by the smaller,

extract the square root of the quotient, and multiply the quantity thus obtained by the length of the turn.

In order, therefore, to find the length of turn required for a gun with a calibre 4·2 inches in diameter, which is to be used for firing a similar shot or shell as another with a bore 1·2 inches in diameter, for which the proper length of turn has already been ascertained to be 64 inches, divide 4·2 by 1·2. The quotient is 3·5, the square root of which—1·87—multiplied by 64, gives the length of the turn 119·7 inches, or ten feet within a fraction.

This then will be the proper length of turn for a gun having a bore of 4·2 inches in diameter, destined for use with that particular kind of projectile for which a turn of 64 inches in length has been ascertained to be the best, when propelled from a gun with a bore 1·2 inches in diameter; and the proper turn for guns of any other calibre may be found in a similar manner.

The following is a scale of the different lengths of the turn required for guns of different calibres, according to the above method, taking the Enfield rifle as a standard, and supposing leaden shot of a form similar to those used with that rifle to be employed. The fourth column shows the smallest turn which could be used with effect for cannon of corresponding calibre, from which the compound shells, represented in Plate II., Figs. 4, 5, and 6, would be fired.

Description of Guns.	Diameter of Bore.	Length of turn for Leaden Shot.		Smallest turn for compound Shells for Guns or Mortars.	
	ins.	ft.	in.	ft.	in.
6-Pr.	3·66	16	4	11	6
9 „	4·2	17	3	12	0
12 „	4·62	18	3	13	0
18 „	5·29	19	8	14	0
24 „	5·82	20	6	14	6
32 „	6·41	21	6	15	3
42 „	6.97	22	6	16	0
56 „	7·65	23	6	16	8
68 „	8·12	24	4	17	0
8-Ins.	8·	24	3	17	0
10 „	10·	27	0	19	0
12 „	12·	29	6	20	9
13 „	13·	30	6	21	6

In forming a rough estimate of the comparative turns required for different kinds of projectiles, it may be taken, as a general rule, that for shot of the same length and diameter, but of different density, the turn will vary nearly inversely as the square root of their weight, all other circumstances, such as the position of the centre of gravity, &c., being the same.

The diagrams in Plates I. and II. are intended to represent the different degrees of rotary velocity acquired by the shot, and the effect produced in the gun by an increase in the calibre, accompanied by turns of different angles.

In order, however, to render the diagrams intelligible, it should be remarked that the figures A, B, &c., represent portions of barrels of different

bores, cut through in a longitudinal direction, and then laid open, so that instead of a cylindrical, they shall present a flat surface. This suggests itself as the easiest method of showing, in the most distinct manner, the angle which is formed by the inclination of the turn.

As we may suppose that the proper angle for the turn has already been discovered and applied in various instances, as, for example, in the case of bullets upon Mr. Whitworth's principle, which require, (with a calibre of .45 in.,) a turn 20 inches in length; Colonel Jacob's, which requires a turn of 3 feet; and that of the Enfield musket, which has a whole turn in 6 ft. 6 in. only; * we may infer that each has its most suitable angular velocity imparted to it, since it is only reasonable to believe that each has been amply tested by experiment. Under this impression, therefore, we may fairly assume that the turn for bullets of the diameter of those just mentioned will, for practical purposes, vary between those of Mr. Whitworth, as the *maximum* turn, and those of the Enfield musket as the *minimum*. As in these diagrams it is necessary for the purpose of illustration to have a standard, I have taken the angle (or nearly so) of the turn for Mr. Whitworth's bullet, or the

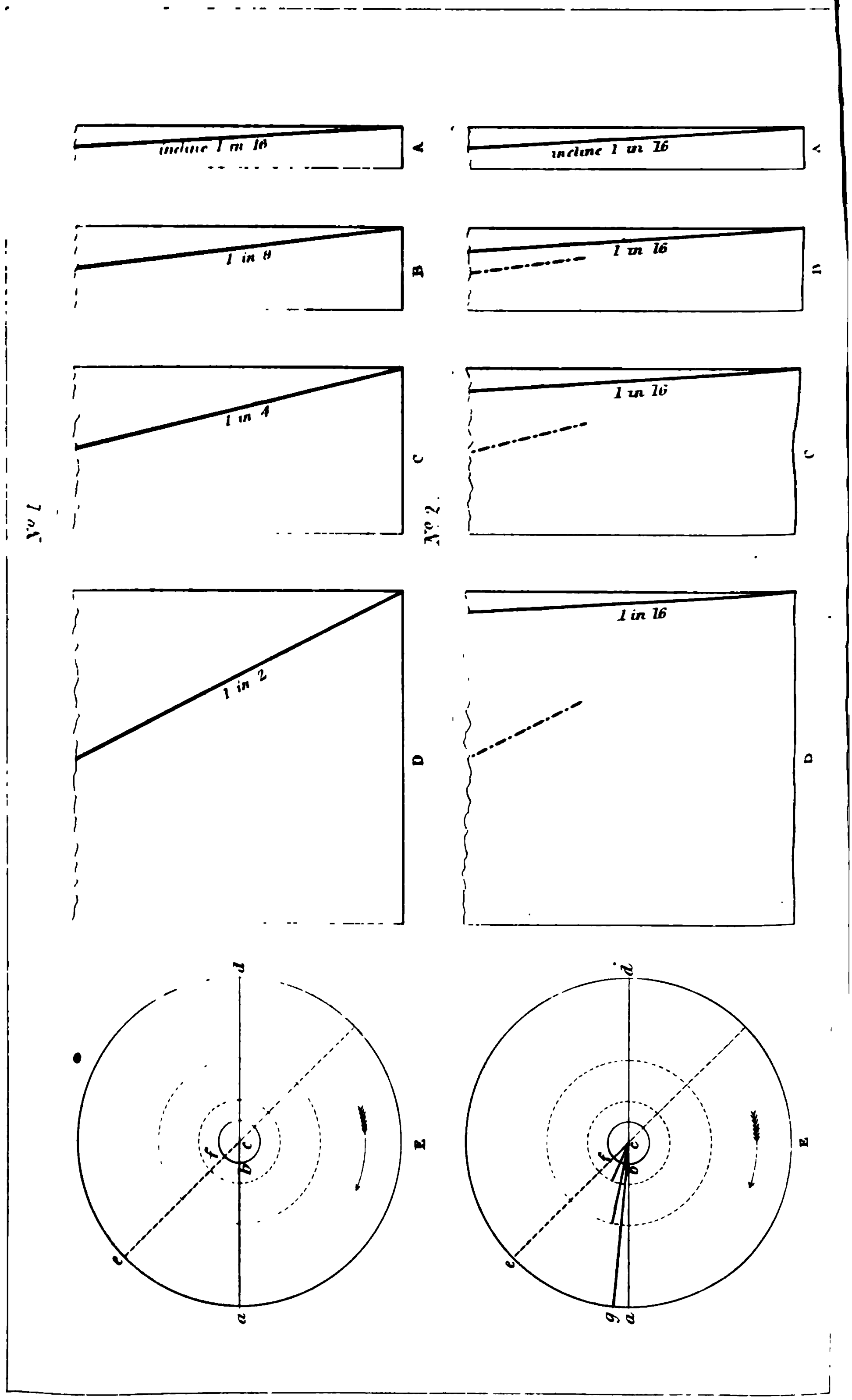
* From the circumstance that the barrel of the Enfield musket is 3 ft. 3 in. in length, and the turn 6 ft. 6 in., it suggests itself as probable that the length of the turn was determined in some measure by the length of the barrel; that is to say, *half a turn* was given to the grooves, without reference to the *exact* turn which the bullet required.

maximum turn, as most suitable for the object in view.

Of these diagrams, then, figure A, in plate 1, represents the angle formed with the axis of the bore by a turn of 2 feet, in a barrel of a half-inch bore; figure B, the angle formed by a turn of the same length, in a barrel of twice the diameter; and figures C and D, angles formed by turns of a similar length, in guns increasing in the same ratio. Of this diagram it need only be remarked, that shot fired from guns varying in their bores, in the relative proportion which is here shown, will all acquire the *same* angular velocity—supposing the velocity of projection to be the same in each instance.

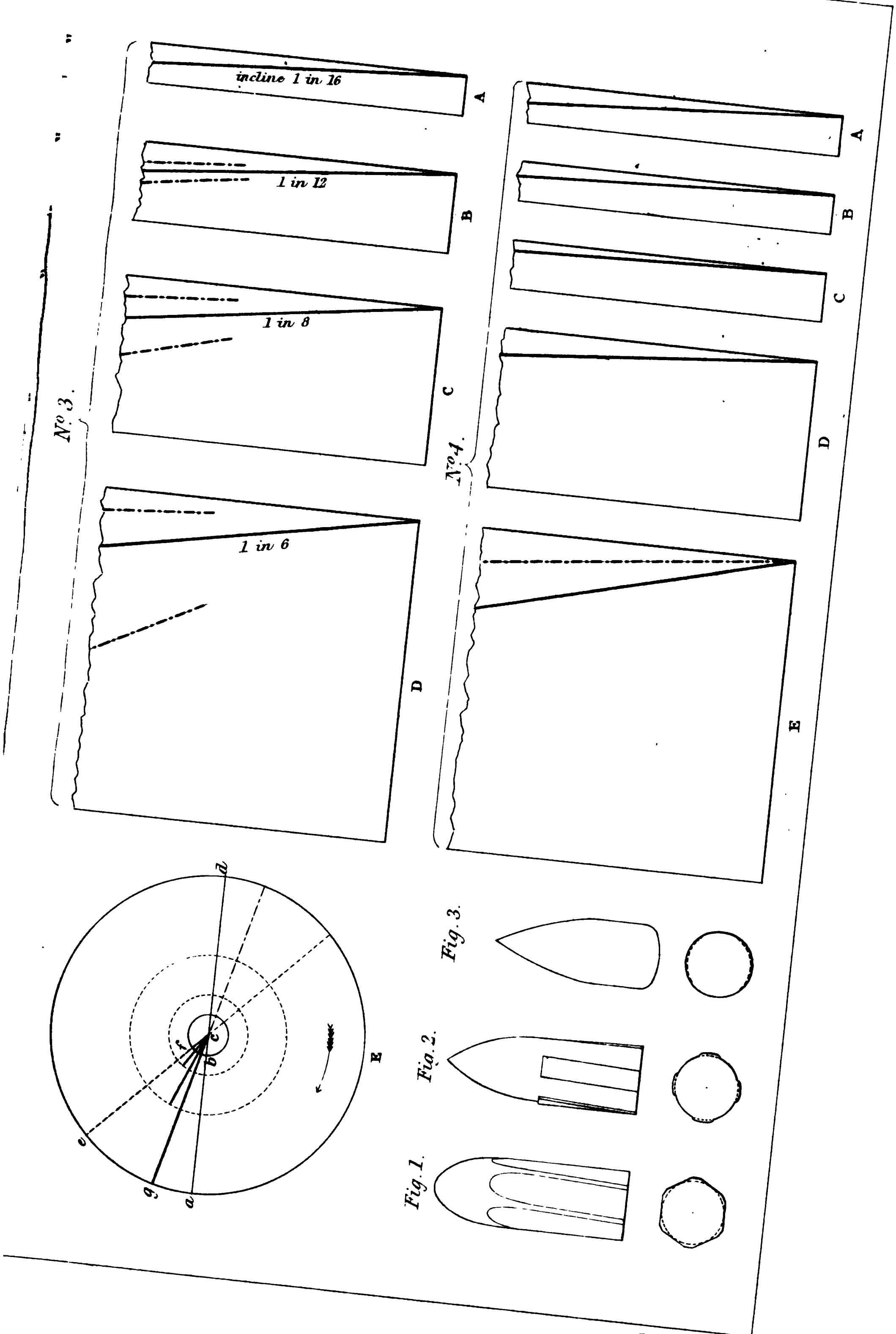
In plate 2, diagram No. 2, fig. A represents a barrel of the same bore, with a turn of the same length as that of fig. A in No. 1. Figs. B, C, D represent portions of barrels of similar size to those denoted by the corresponding letters in No. 1, only here, the *angles* formed by the turn are the same in each figure. In this case, the angle of the turn being the same in each instance, it will be seen that the angular velocity will be diminished inversely as the diameter of the shot is increased.

In plate 2, diagram No. 3, the figs. A, B, C, D represent portions of barrels corresponding in size with those denoted by the same letters in the two former diagrams. Here fig. A shows an angle of the same magnitude as in the former cases; but figs. B, C, D show the magnitude of the angle when the length of the turn increases as the square root of the calibre.



J W Lowry sculp[t]

Plate 2.



J. W. Lowry, sculp^{t}

In diagram No. 4 are shown the different angles formed by the turns adopted for several kinds of shot of various sizes—A, Mr. Whitworth's; B, Colonel Jacob's; C, the Enfield musket; D, Mr. Armstrong's 2-inch gun; and E, Mr. Whitworth's rifled 4-inch gun. The dotted line represents the turn employed for a 4·2-in. gun rifled at Woolwich (after the author's design), for experimental purposes.

In the diagrams 1, 2, and 3, the fig. E is intended to represent the relative angular velocity which would be acquired by rifled projectiles, of different sizes, supposing them to be fired from guns with turns which vary in the proportion of those shown in figs. A, B, C, and D, in each diagram.

To explain this figure, a line *a*, *b*, *c*, *d*, is drawn through the common centre of all the circles, and intersected at *c* by another line drawn at any angle, as *a*, *c*, *e*.

In fig. E, No. 1, the angular velocity produced by the different turns being in each case the same, the largest shot (the velocity of projection being the same in each case) will describe the arc *a*, *e*, in the same space of time as that in which the smallest will describe the similar arc *b*, *f*.

The angular velocity given by the different turns shown in No. 2 being diminished in a proportion as the diameter of the shot, the largest shot will describe the arc *a*, *g*, in the same time as the smallest will describe the arc *b*, *f*.

In No. 3, where the angular velocity of the different

sized shot varies as the square root of their diameters, the largest shot describes the arc *a, g*, in the same space of time as the smallest describes the arc *b, f*. In this case it will be seen that although the inclination of the turn is considerably increased, the angular velocity of the shot is diminished.

In fig. E in each diagram, the relative angular velocity of four shots of different sizes is given, but it appears needless to institute a comparison between more than two, inasmuch as these are sufficient to illustrate the relative angular velocity of each shot.

In diagram No. 1 it will be observed that the angle formed by the groove with the axis of the bore increases so rapidly, that it is evident if shot of all sizes absolutely required the same angular velocity, the principle of the rifle could never be successfully applied to cannon.

In diagram No. 2, where the same angle is formed by the turn in all guns irrespective of their calibres, it is evident that the angular velocity must be diminished in too great a degree; for if the angle there shown is necessary for shot of the smaller size, what reason can be assigned for giving so small an angular velocity to shot of increased diameter? The size alone of the shot would make no difference in the angular velocity required for it, unless it were productive of some different result; and we know (with respect to the flight of projectiles) that the difference produced by size is chiefly, if not entirely owing to the

diminished effect of the air upon the projectile, and this, as I have endeavoured to prove, is in a much smaller proportion than *as* the calibre.

The true proportion is seen in diagram No. 3, where, in conformity with it, the length of the turn increases in the ratio of the square root of the calibre. Even in this case it may be remarked that the angle of the turn is increased to a degree, which would make the application of the principle of the rifle difficult with guns of more than a certain calibre—of a calibre, however, not likely to be employed.

Though a large gun rifled with a much smaller turn than would be given by the method I have described, may project a shot, with the same accuracy that would be attained with a gun of smaller calibrè, at equal distances, yet this is by no means a proof that such a turn is sufficient to give the larger shot the proper degree of rotary velocity. A large gun should throw its shot with the same precision as the Enfield rifle, (or any other which may be taken as a standard,) not at the same distance only, but at the ranges which would be acquired by the same elevation of the gun in each case; that is to say, a gun with a bore 4.2 inches in diameter (or 9-pounder) should throw an elongated shot—the weight of the shot, and the charge of powder being proportionate to that used with the Enfield musket—to a distance of about 2000 yards, with the same accuracy as that which is attained by the latter at 900 yards, the degree of elevation at

which these respective ranges should be acquired, being nearly the same for each arm; some allowance, of course, being made for the friction consequent upon the greater comparative turn used with the larger gun. Until this, or an approximate result, be obtained, the proper method for rifling cannon cannot be considered to be established.

With hollow iron shells, however, the accuracy of a musket bullet could never be obtained at these distances, inasmuch as a want of density and concentricity is productive of great irregularity in the flight of rifled projectiles; and these defects, together with those which arise from the windage, are so prominent in the above kind of projectiles, that no turn, however great, would afford a remedy for them; these, however, might perhaps, obtain some advantage over *spherical* shells.

In a small work of this kind, it is impossible to enter into a complete investigation of a subject which involves so many considerations; all I have attempted is to give a general outline of the method which appears to me to be the correct one of applying the principle of the rifle to cannon, and I will conclude my remarks upon it by briefly summing up the principal points which I consider worthy of particular attention.

First, then, as a general rule, we find that the length of the turn of the rifling in guns of different sizes should be in the ratio of the square roots of the diameters of the bores of the guns.

In the second place, we find that the turn will, ac-

cordingly, be greater in proportion to the size of the gun as the diameter of the bore increases, thereby causing it to have an increased angle in large guns, in a ratio about at the square roots of their calibres.* The initial velocity of the shot, and the elevations at which they are fired being supposed the same, the velocity of rotation communicated to large shot by the greater comparative turn imparted to them, will be made at the expense of their velocity of flight and range.

Thirdly; that the weight and form of the projectile having the chief influence on the turn, that form is preferable which will require the least turn; it being important to avoid, as much as possible, increasing the angle, in proportion as the size of the gun is increased.

Lastly, it may be remarked of projectiles of a given length, that those which require the least turn are, first, those of the most perfect concentricity, and the surfaces of which offer the least resistance to the air, thereby suffering the least impediment in their rotary

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* Let α be the angle that the grooves of the rifling make with the axis of the gun, and l the length of the turn, d the diameter of the bore; then tan. $\alpha = \frac{\pi d}{l}$. But the rule here explained and proved gives $l \propto \sqrt{d}$, whence tan. $\alpha \propto \sqrt{d}$; and since the angle of the grooves is generally small $\alpha \propto \sqrt{d}$, nearly.

For this, and the formula given in page 43, as well as for many valuable suggestions, I am indebted to my friend Mr. T. B. Sprague, Fellow of St. John's College, Cambridge.

motion; secondly, those which have their centre of gravity in their fore part, as their stability is greater, and consequently they require less turn to keep the axis about which they rotate, steady; thirdly, those of which the form approaches more nearly to a cylinder, as in them the accumulated work (due to the rotation) is greater than in any other form of shot of the same diameter and length, and they consequently require a less turn than is the case when they are made in the form of a lengthened cone; fourthly, those which have the greatest density; *e.g.*—a leaden bullet will require less turn than an iron one, for the work accumulated in producing the same angular velocity in the two will be greater in the lead, than in the iron one, while the forces opposed to the rotation of the two are (or may be supposed to be) the same. The less prominent the foregoing qualities appear in shot, the greater will be the turn required, although some of those qualities have a greater influence upon the turn than others.

In applying the principle of the rifle to cannon, it appears, that in using even the smallest effective turn for the most favourably formed shot, the increase of its angle will give a limit to the length of the gun. In fact, the turn required for a gun with a bore of from twelve inches upwards, would be so great in proportion to its size, that it would be necessary to reduce the length of the bore in proportion to the increase in the angle of the turn, so that in extreme cases the gun

would be reduced almost to the dimensions of a mortar. This would necessarily result in order to avoid the very great increase in the friction, &c., which, if the gun were of a proportionate length, and fired with the ordinary charge of powder, would be occasioned by the increased angle of the turn.

In a word, all these circumstances tend to show how important it is to acquire in the first instance a knowledge of the due length of turn required to keep the projectile true during its whole flight, for it is only by availing ourselves of this knowledge that the greatest effect is to be obtained with rifled ordnance, since too great a turn will cause great friction and a diminished range, and too little, a want of accuracy.

It only remains for me to suggest a simple course of experiments, by which the principle I have already enunciated may be tested and established; and I may add, by the way, that such experiments as I would propose, in order to ascertain the proper angular velocity which should be given to shot, would be rendered, by a fixed system of conducting them, much less complicated and expensive than any vague series which might be undertaken without reference to facts derived from scientific conclusions, and in the vain endeavour, by an endless and uncertain process, to arrive at any satisfactory or conclusive results.

It must indeed be obvious to all who have a practical knowledge of this subject, that such experiments as these would be interminable, and that they would

involve an endless expenditure, both of time and money, before any satisfactory data could be obtained, supposing it possible that such could *ever* be thus acquired.

In reference, moreover, to the experiments which I am about to propose, I would remark that they may be made with any kind of shot similar in form and weight. It would be of little consequence whether the shot were of solid iron, or a compound of iron and lead; for it must be remembered that these experiments would be solely for ascertaining the exact ratio according to which the length of the turn, as dependent upon the size of the shot, should be increased or diminished, which ratio will of course be always the same, of whatever material the shot may be formed.

I will proceed briefly to notice the manner in which the experiments should be conducted; and I think I shall be able to indicate the most simple and advantageous method for ascertaining what relative proportions in the length of turn would be the most conducive to insure the best and most uniform effect in guns of various diameters.

For this purpose, then, I would propose to have a certain number of guns—say seven 12-pounder brass howitzers, bored each with a 2-inch bore, and rifled with grooves of the same form, but different turns. For these seven guns, the greatest turn should be three, and the least, sixteen feet in length; whilst the intermediate turns will be respectively, four, six, eight, ten, and

twelve feet. I give these different lengths advisedly, as they comprehend all the different degrees to which the turns used for small arms could be reasonably reduced, supposing such to have their bores increased to the above-mentioned 2-inch diameter, allowing, of course, for the difference of density between an iron or compound shot, and a leaden bullet.

Upon a general view of the question, it will, I think, be found that the most effective length of turn for any kind of shot, of this diameter, which can be available for practical purposes, will be somewhere between these two points (viz., the 3 and the 16-feet), provided the shot does not exceed three of its diameters in length. If, however, the shot selected for such experiments be of iron (*i.e.* unexpanding), or more than two of its diameters in length, in that case the length of the different turns used for the above guns might be respectively, 3, 4, 5, 6, 7, 8, and 9 feet.

Supposing then that the guns are bored and rifled according to the plan which I have suggested, I should deem it advisable that each should be fired with the same charge and elevation, and that this charge should be the greatest that would ever be practically used; also that the elevation should be the highest which would be used in practice with such a charge.

I would give this elevation (say about 15 degrees) because it is proved that the length of turn which is suited to a shot fired with such an elevation, will be found to be amply sufficient for it when fired with any

lower elevation, but not *vice versâ*. For it has been shown by numerous experiments that a given velocity of rotation may keep a bullet true for a certain distance, but that by elevating the gun, and thus increasing the *range*, a greater turn will be rendered necessary, and that the longer the shot the more noticeable this fact will be.

Having in this manner ascertained what is the least, and therefore the best, turn which could be used for the shot, the next step will be to endeavour to arrive at the exact ratio of decrease in the angular velocity or inclination of turn which should be assigned to shot of similar form and density upon any increase of their size.

For settling this question, three or, at least two guns would be necessary, and these might be 24-pounder howitzers, with bores 4 inches in diameter, or twice the size of those employed for the first portion of the experiment.

In rifling these guns, the same kind of grooves should be used as those employed in the first instance, but the turns given to them should be in the following proportions—there being, in fact, none other for which any reasonable grounds can be assigned.

The first gun should have a turn of the same length as that which has been decided, by the test of the last experiment, to be the best, provided it be not (for mechanical reasons) too great to use with the larger gun; and as it will be necessary to take some standard as an example, let us assume, for the sake of illus-

tration, that one whole turn in 6 feet has been ascertained by the first part of the experiment to be the best.

Then the second gun (in reference to our assumed standard) should have a turn of 12 feet, or in a proportion commensurate with the increase of the diameter of the shot.

The third should have a turn of 8 feet 6 inches, that is to say in a ratio as the square root of the increased diameter. These two (or three) guns should each be fired with the same elevations and proportionate charges of powder as those used with the seven smaller ones already mentioned.

By this simple course of experiments, the correct ratio, according to which the turn for guns of various sizes should be regulated, will be easily ascertained, and I am fully convinced that such experiments will firmly establish the truth of the principles which I have laid down.

In such experiments, however, as those to which I have just referred, although the difference between the turns of the three larger guns may not be apparently very great, yet the case will be vastly altered when the bores differ from each other more considerably in their diameters. Hence, therefore, in order to render the trial as satisfactory as possible, the difference between the bores of the guns used for the experiments should be made as great as they conveniently can be. The guns used by me in these experiments, although of

smaller dimensions, differed more in the sizes of their bores than those just mentioned.

If, however, it be not convenient to make use of guns of a large size, it will be requisite that the correct turn should be ascertained in the first instance with a much greater degree of exactness. Thus, if 6 feet is found to be better than 4 or 8, still this does not determine positively that 6 feet is absolutely the best length for the turn, but only that it will be somewhere between 4 and 8 feet, so that it will be advisable to try an intermediate turn, such, for instance, as 5 or 7 feet, and so on, until the most correct turn may be as nearly as possible ascertained.*

From this it will at once be seen, that if the carrying out of a single course of experiments relating only to one particular point, even when conducted upon a fixed system as simple as it can be made,—may, when great exactness is required, necessitate the making a subordinate series of experiments; how infinitely complicated the matter will become when experiments are made, not only without reference to the settlement of any distinct point, but with the ill-advised intention of attempting to overcome every difficulty at

* The margin—if I may so term it—for the length of turn is, of course, greater as the size of the bore of the gun increases: thus, if a few *inches*, more or less, in the length of the turn of a rifle musket will make no perceptible difference in its firing; the difference made by a few *feet* more or less in the length of the turn of a gun of a proportionately larger size would be equally imperceptible.

once; and from this also some idea may be formed as to the incalculable loss, both of time and money, which would necessarily result in endeavouring to carry out experiments based upon no scientific grounds, conducted upon no fixed principle, and therefore liable utterly to fail in accomplishing the object which they have in view.

Since I have insisted so much upon the necessity of all experiments being conducted upon some fixed system, founded upon scientific as well as practical data, I would now briefly state the grounds for my advocating that particular system, which I have myself found by personal experience to produce the most satisfactory practical results.

It will be found that the length of turn to be given to the grooves will depend upon three points, viz.:—

First, *the kind of shot.* On this account, therefore, any set of experiments undertaken, for the purpose of ascertaining certain points connected with the turn of the grooves, must be made with the *same kind of projectile.*

Secondly, *it will change with every variation in their size.* Hence, in making the necessary experiments for ascertaining the turn required under these circumstances, the various conflicting arguments, in favour of the different ratios of variation in the angular velocity or turn required for the shot, should be taken into consideration, and those for which any plausible reason can be assigned should be tried by a method similar to that which I have proposed.

Thirdly, *it will differ with every different elevation of the gun.* For this reason, as the turn required for great elevations is greater than that for small, in experiments for ascertaining the proper degree of turn, the gun should always be fired with the greatest elevation which would be used in practice.

It must also be noticed that the *velocity of projection* is to be considered, in giving a certain length of turn; for when that velocity is greatly increased, it will not be safe to use the same degree of turn as may be employed with a lower velocity, as the shot will be liable to strip, or the gun to burst under these circumstances.

Therefore, in making experiments, the highest velocities which would be practically used, should be also employed in such experiments.

With regard, then, to the experiments which I have thus suggested, I would merely add that, whatever be the precise ratio of angular velocity to be given to shot, these experiments are best suited for its discovery; and when the proper ratio for the turn of the grooves is once ascertained, any further experiments which may be made need only be carried on for the purpose of testing what are the best mechanical appliances for improvements in the projectile, and in the form of groove, in order to reduce the friction as much as possible.

In conclusion, I would add, that as all matters connected with this subject may in reality be said to resolve themselves into a question of *friction*, and as

the quantity of friction will depend chiefly upon the degree of turn, so that system for rifling ordnance will be the best, which, whatever be the mechanical means used for giving the shot its rotary motion, will lead to the employment of such a degree of turn only, as will produce the least possible quantity of friction, and at the same time secure the greatest possible amount of practical efficiency.

It is to be remarked, that besides the *friction*, properly so called, of the shot against the grooves, there is a very great diminution of the velocity from the *resistance* of the grooves, whereby the motion of the shot is altered from a simple forward motion to a rotary one. This effect increases rapidly as the turn of the rifle is increased, and all that has been said above as to the frictionof the grooves is applicable also to this action.

Reviewing the preceding observations, it appears impossible to apply any *strictly* accurate rule for the regulation of the length of the turn for guns of different calibres. As long as the problem of a shot's trajectory remains unsolved, no perfectly correct mathematical formula for the length of turn can be found; and even if we had such, it would be of small service, unless each gun were fired invariably with a fixed elevation, and an uniform velocity were given to the shot; an extremely nice calculation would give a difference in the length for every velocity of the projectile, and for every elevation of the gun. Practically, therefore, we can only apply a rule based upon a general principle.

As it is evident that the greatest turn is required for high velocities, and we find that, when fired with these velocities, the shot are affected by the resistance of the air in a ratio as the square root of their diameters nearly, we may consider that the ratio which has been assigned for the length of the turn for different guns is the best, as being the only one which is suited to meet all contingencies.

As there have been one or two claimants to its formation, I am induced to state that this theory of regulating the angular velocity of shot of different sizes, according to the quantity of the retarding or the deflecting force of the air upon them, was first put forward by myself, and that no publication has as yet come under my notice which shews that this or a similar theory was ever previously put forward by any other person.

In 1854, wishing to have a large gun rifled, I endeavoured in vain to obtain any information which might serve as a guide for this purpose—the rifling of all experimental cannon having been, apparently, regulated by caprice alone—no theory of any kind being in existence. This circumstance led me to make experiments on the subject, which resulted in my adopting the above theory as the most correct, as well as the most suitable for practical purposes.

ON THE PROJECTILE.

Assuming that the principles laid down in the preceding pages are correct, it remains to determine the best principle to be followed in the construction of the projectile. The difficulty of obtaining a shot or shell combining all the necessary qualifications, has hitherto proved one of the main impediments to the more extended use of rifled cannon. It will be evident to all who have given their attention to the subject, that to render an elongated projectile as efficient as possible it should combine the following qualifications:—

1st.—It is indispensable that it should be of not less than a certain density or specific gravity, in order that a proper degree of range may be obtained with it.

2ndly.—Its axis should coincide perfectly with the axis of the bore before leaving the gun, and, therefore, it must completely *fill* the bore, otherwise its flight can never be depended upon; hence the fatal objection to homogeneous shot of a non-expanding metal. The want of this coincidence in long iron shot also tends greatly to burst the gun.

3rdly.—Its centre of gravity should be thrown for-

ward before its centre of figure, in order to give it greater stability, and less inclination to turn over, and also to ensure that the axis about which the shot rotates should always be a tangent, or nearly so, to its line of flight. The forward position of the centre of gravity will also allow of the use of a less turn in the rifling, which is an important object in guns of large calibre. It is evident that the position of the centre of gravity will make a great difference in the velocity of rotation required for long shot; for the more forward the centre of gravity is in the projectile, the smaller will be its inclination to rotate about its shorter axis; the rotary velocity which is required to give the shot the necessary stability will, therefore, be less. There are also other reasons why the centre of gravity should be in the fore part of the projectile, which will be noticed hereafter.

4thly.—Assuming the necessity of employing a compound shot or shell, an even expansion of that portion of the shot which is to take the grooves is absolutely necessary; for unless the axis of the shot be made to coincide exactly with the axis of the bore immediately upon its receiving the impulse from the powder, the chief advantages attending the expansion will be completely neutralized.

Lastly.—It should be of a form offering as little resistance to the air as possible.

These appear to be the chief requisites for projectiles which are used with rifled cannon. It is obvious, that

if the same range, and uniform steadiness of flight, could be acquired by a solid iron, as by a compound shot, the former would possess several practical advantages over the latter. This, however, cannot be the case, since they are deficient in a qualification which, with rifled guns, is of paramount importance: they cannot be exactly fitted to the bore of the gun, and, therefore, can never be driven out of it in a perfectly straight direction. Sufficient windage must always be allowed for the fouling of the bore, and its contraction when heated, even in breech-loading guns; and this being the case, a round shot can only come in contact with the interior of the gun at one point, and an elongated shot at only two points (or along a line) at the same time. A long iron projectile, therefore, can only have its axis coincident with the axis of the bore (which is also that of its line of flight) when it is in such a position as either not to touch the gun at all, as in Fig. 7, Plate 3, or to bear upon the grooves only, as in Fig. 8; positions which may be accidentally assumed by the shot, but which it cannot be compelled to assume.* The axis of the shot will thus shift during its passage through the bore; the effect of which will be that the axis about which the shot receives a rotation, will not coincide exactly with the

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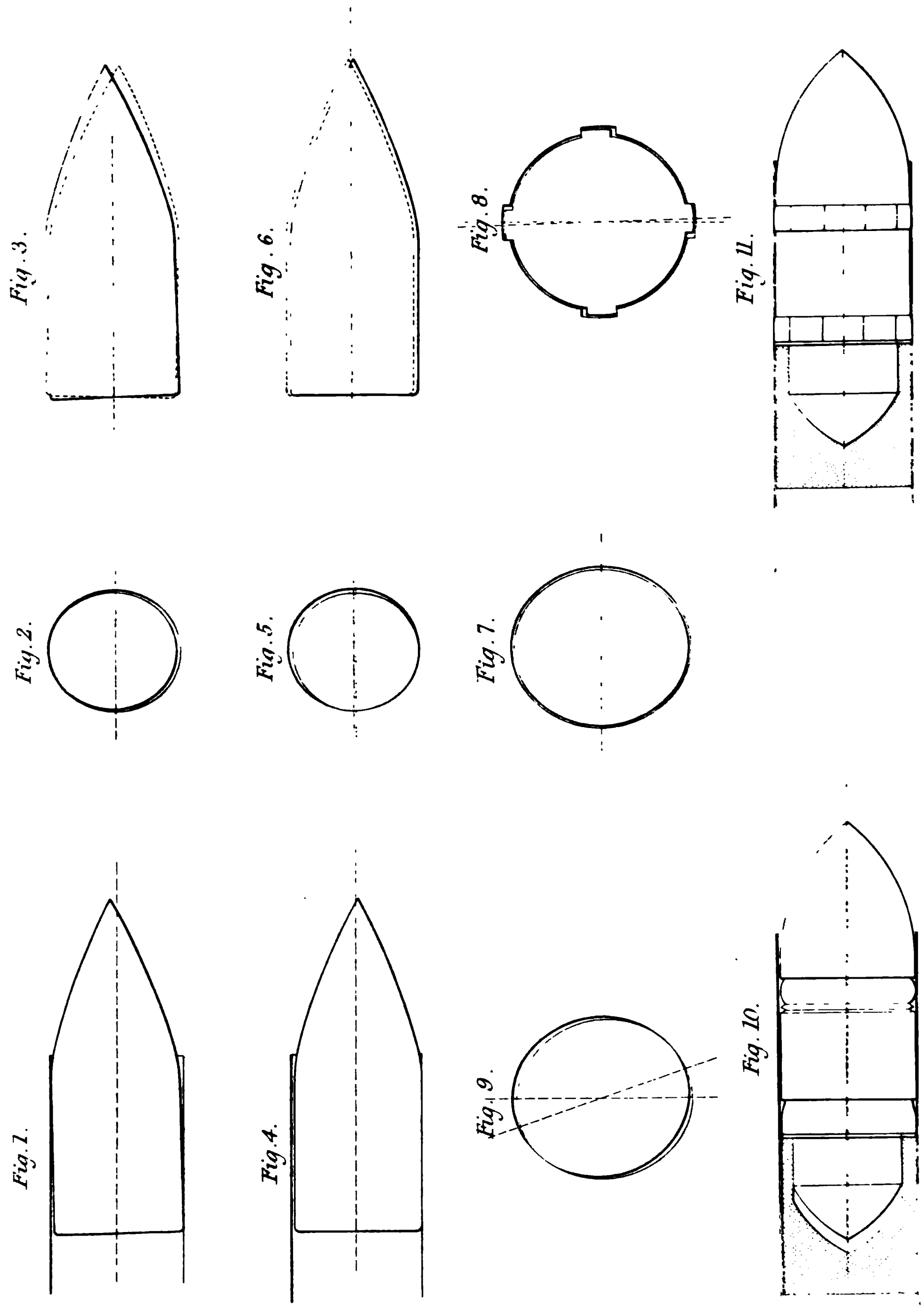
* Fig. 9, Plate 3, represents the same conditions in an elliptically bored gun, as Fig. 8 represents in a grooved gun.

axis of the shot or of the bore,* and unsteadiness of flight will follow, which will require a greater turn, and will at the same time cause the resistance of the air to be greater. No patch or wadding will remedy this defect.

Although the incorrectness in the flight of iron shells may be lessened by calculating minutely the contraction and fouling of the bore of the gun, in order that the windage may be reduced to its minimum; by constructing the shells with great nicety; by having the centre of gravity as far forward as possible, in order that the pressure of the air upon the hinder part of the projectiles may tend to correct the unsteadiness arising from their not completely fitting the bore of the gun; still, under no circumstances can they be made to have so true or so prolonged a flight as compound shot or shells, on account of the irregularity produced by the windage, as well as from the friction resulting from the greater degree of angular velocity rendered necessary on this account.

Thus the turn used with the Lancaster gun, although, perhaps, great enough to cause the projectile to fly point foremost for a certain distance, is clearly not sufficient to remedy the defects resulting from the windage. The name acquired by this shell in the Crimea, the "Express train" (from the noise which it makes,

* Figs. 1 to 6, Plate 3, represent some of the different positions of the shot, both before and after leaving the bore.



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and which is occasioned by its *wabbling* motion), is sufficient evidence of this fact; for the flight of rifle shot is only accompanied by this peculiar noise when the longer axis of the shot is not coincident with its line of flight. The noise made in the air by a rifle shot when its motion is even, nearly resembles the "whish" of an ordinary round shot, attended, in most cases, with a slight vibration.

I think it doubtful if *any* velocity of rotation will completely counteract the irregularity of movement, caused by the windage, in the flight of iron shot.

The difficulty and loss of time which must always attend loading with these shells seems, too, almost to disqualify them for any description of ordnance except for those in which a quick service is not of the first importance, such as heavy mortars, or guns used with high elevations only.

There is a circumstance attending the flight of all shot, when fired from rifled guns, which requires more particularly to be noticed where elongated projectiles are used, viz., when the centre of gravity in the shot is at, or behind, the centre of its figure, the axis very soon ceases to coincide with the tangent to the trajectory; this not only impairs the range and accuracy of the shot's flight, but when percussion shells are used, prevents them, when fired at great elevations, from falling point foremost upon the object aimed at.

Robins notices this in his remarks upon the rifle, where he says, "that though the bullet impelled from them (rifles) keeps for a time to the regular track with sufficient nicety, yet if its flight be so far extended that its track is much incurvated, it will then often undergo considerable deflections. This, according to my experiments, arises from the angle at last made by the axis upon which the bullet turns, and the direction in which it flies; for that axis continuing nearly parallel to itself, it must necessarily diverge from the line of flight of the bullet, when that line is bent from its original direction; and when it once happens that the bullet whirls on an axis which no longer coincides with the line of its flight, then the unequal resistance described in the former papers will take place, and the deflecting power hence arising, will perpetually increase as the track of the bullet, by having its range extended, becomes more and more incurvated." See *a*, Fig. 5, Plate 4.

Robins proposed a remedy for this in his egg-shaped bullet; but from the remarks of the author of "*Scloppetaria*," it appears that it met with indifferent success, and that (owing no doubt to the difficulty of preserving the coincidence of the axis of the bullet, and that of the barrel of the gun,) its flight varied very much. The same writer observes that this bullet, unlike others, always flew to windward. In the Pritchett bullet, which possesses the advantages without the defects of the egg-shaped bullet, the centre of gravity is thrown

slightly forward, but hardly sufficient to give proper effect to shot when fired at great elevations.*

Some writers have contended that, whatever may be the position of the centre of gravity of an elongated shot fired from a rifle, its axis will always be a tangent to the line of flight; but this opinion is clearly erroneous. If the shot were projected in a vacuum, its axis would always be parallel to itself, notwithstanding the rotation of the shot about its axis. The resistance of the air has more effect on the light end of the shot than on the heavier end, and, therefore, will tend, when the centre of gravity is in the hinder part of the shot, to raise the point instead of to depress it; besides the resistance of the air, there is no cause that will operate to alter the position of the axis of the shot, and prevent its remaining parallel to itself, throughout the whole of its flight.

The position of the centre of gravity, therefore, is of great consequence with projectiles which are fired at great elevations, not only because it ensures the axis of the shot being a tangent to its line of flight, so that the resistance of the air is reduced as much as possible; but also because the deflection of the projectile depends very much upon it.

After a shot leaves the gun, the action of the air affects it in a threefold manner; in the first place, it offers a resistance against the fore end, caused by its

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* Appendix A.

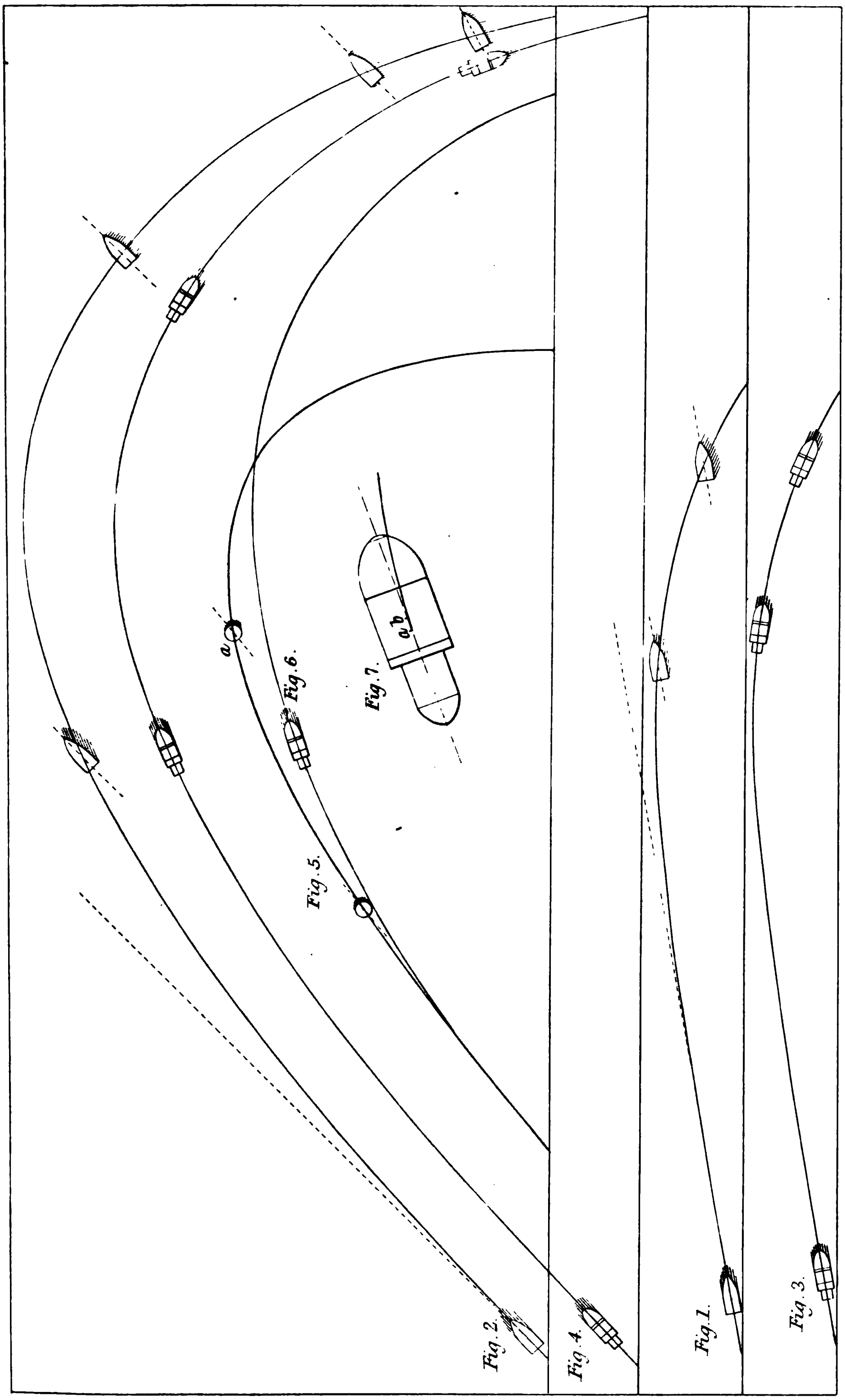
flight in a forward direction, this being in proportion to the surface of the transverse section of the shot, and as the square of the velocity of its flight, nearly; secondly, there is a pressure upon the longitudinal surface of the shot; and, thirdly, it exerts a pressure upon its under surface, produced by the falling movement caused by gravitation, which is exactly the same as it would be subject to on falling to the ground under any other circumstances, as for instance, from rest.

The result of these different forces is an oblique pressure upon the fore and under part, and is attended by a diminished pressure upon the upper portion of the shot's surface. (*See* Figs. 1 and 2, Plate 4.) The direction of the pressure upon the under surface of the shot varies with the inclination of the longer axis to the vertical, and it is only when the shot rises or falls vertically that this pressure is solely upon the extreme end of the shot.

This oblique pressure tends greatly to increase the deflection of long projectiles, and its effects can only be reduced to a minimum by forcing the fore end of the shot continually in the direction of the pressure, so that the smallest possible surface of the shot is opposed to it. (*See* Figs. 3 and 4, Plate 4.)

This can be done, either by diminishing the weight of the hinder part of the projectile, so as to allow of its having more length behind its centre of gravity, or (with iron shot) by increasing the resistance of the air upon the part behind its centre of gravity, by

Plate 4.



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means of the projections. The pressure of the air, consequent upon the falling movement, will thus be greater upon that part of the shot behind the centre of gravity than upon its fore part, and so the former will be gradually retarded in its descent, and continually keep the longer axis of the shot coincident with the tangent of its line of flight.

It is a remarkable circumstance, that rifled projectiles, even those of the most perfect construction, are invariably deflected in the direction of the turn of the grooves, that is to say, with a right-handed turn, where the upper part of the shot turns from left to right, the deflection will be to the right, and *vice versâ*. The interesting experiments made by Professor Magnus of Berlin, relative to the cause of the deflection of projectiles ("Naval Gunnery," by Sir H. Douglas, page 64), are the most remarkable of any that have been made on this subject. A full description of them (which would be too long to insert here,) may be seen in Taylor's Scientific Memoirs, for May 1853. These experiments were made with bodies in the form of projectiles placed in moveable frames, and the results were obtained by means of a current of air directed against them.

Professor Magnus's explanation may be described briefly, as follows:—It is well known that when a body, such as a solid of revolution, is rotating rapidly, any force which acts upon it in a direction passing through the axis, but not through the centre

of gravity, will not have the effect of moving the axis in that direction, as it would do were the body at rest, but will cause the body to move to one side, so that if the centre of gravity is fixed, the axis will describe a cone about the direction of the force. This may be seen in the motion of a common top, spinning with its axis in an oblique direction. When a force is applied to the top in this position, as, for example, if a current of air is directed against it, vertically downwards, the effect will be to depress the axis very slightly, but to increase the velocity with which a top, spinning in such a position, will move laterally. It appeared from Professor Magnus's experiments, that in a bullet of the ordinary form, the pressure of the air on the fore part has a tendency to raise the apex of the shot; but this pressure, agreeably to what is stated above, will not have the same effect when the shot is rotating rapidly; but supposing the rotation to be from left to right, will cause the apex of the shot to move very slowly towards the right, and consequently produce a deflection of the shot in that direction. If the time of flight were sufficiently long, the apex of the shot would describe a complete cone about the direction of flight, but in general, the time of flight is so small, that the apex only proceeds to move to the right.

The experiments of Professor Magnus are, however, imperfect, as regards the whole subject of deflection: for he has not examined what effect the position of the centre of gravity being very forward in the shot, would

have on its deflection, nor did he experiment with bodies having projections on their hinder parts, such as exist in all rifle projectiles. These experiments therefore, ingenious as they are, do not exhaust the whole subject, and leave much to be done by future investigators.

The theory entertained by many, that the deflection of the projectile, or *derivation*, as it is called by the French, is to be especially attributed to the greater pressure of the air upon the under surface of the shot, is not borne out by the results witnessed in practice;* for if this were the sole, or even the chief cause of the deviation of long shot, the greater their comparative rapidity of rotation, or the quicker the turn of the grooves, the greater would be the deflection; whereas, we find by increasing the rotary velocity of the shot without increasing its translatory velocity—that is to say, by increasing the *turn* only—a contrary effect is produced.

The theory of Professor Magnus perfectly agrees with the results obtained in practice, as the movement to which he ascribes the deflection of long shot, takes place more slowly when the velocity of rotation is higher, so that the deflection arising from it will be less.

When a very high velocity of translation is given to long projectiles, we find in practice that the deflection

* Appendix B.

is much increased. This also is agreeable to the theory of Professor Magnus, inasmuch as the velocity of rotation increases only in proportion to the velocity of translation, whilst the resistance of the air increases in the ratio of the square of the velocity, and therefore the rotary movement he describes would, in this case, be made with greater comparative velocity, and the deflection of the shot in passing over a given space, would consequently be greater.

The rotary movement described by Professor Magnus, although similar in appearance to the one shown in Fig. 3, Plate 3, must not be confounded with it, each resulting from a totally different cause, and differing essentially in their action, the movement of the shot which is represented in the Plate being a quick one,—its point describing a spiral about its line of flight—whilst the other is extremely slow; so slow indeed, that when the shot has a very high rotary velocity, a considerable time would elapse before the apex of the shot would describe a complete circle; probably a longer time than would be occupied by the whole flight of the shot. Instead, therefore, of its apex describing a spiral about its line of flight, it only proceeds to move to one side, when the air presses the centre of gravity towards the same side, and thus causes the whole body of the projectile to deflect from the plane of its trajectory.

In whatever manner, however, the deflection of elongated rifled projectiles is to be accounted for, it

is evident that the position of the centre of gravity must exert a considerable influence on the extent of it.

With elongated iron projectiles, there is always a considerable deflection, *not* always in the same direction. This arises from the *windage*, by reason of which the projectile rarely leaves the gun in such a manner as to ensure a perfect coincidence between its longitudinal axis and the line of flight.

In Plate 4, I have given representations of the positions of several shot as they would appear during their flight. Fig. 1 represents the positions, at the several points of its flight, of a shot having its centre of gravity at or behind its centre of figure. Fig. 2 shews the same shot fired at a greater angle of elevation; the effect becoming more remarkable as the elevation is increased. The pressure of the air being so much greater upon the shot, when the centre of gravity is not sufficiently forward to keep its axis nearly coincident with its trajectory, will cause the flight of long shot to deviate from the plane of the trajectory as well as to suffer considerable reduction. Figs. 3 and 4 represent the positions in its flight of a shot having its centre of gravity sufficiently forward to enable it to keep the longer axis coincident with the line of flight throughout its extreme range. This is a much more important consideration where percussion shells are to be employed at great elevations, than with small arms or guns which are used for horizontal firing only.

Fig. 7 shows a shot moving in its trajectory. If we suppose the centre of gravity to be at its centre of figure (*a*) the shot would continue to rotate about an axis parallel to itself, since there would be nothing to cause an alteration in its position; but if the centre of gravity were situated at some point (*b*), *before* the centre of figure, this would continually tend to bring the fore part of the shot down, and thus to preserve the coincidence between the axis of the shot and the tangent of the curve of its flight. The centre of gravity should be just forward enough to keep the axis a tangent to the trajectory. To have it so far forward as to bring the fore part of the shot *below* the tangent, would cause an unsteady flight, and a diminished range; a similar effect, indeed, to that which would be produced by over-weighting the head of an arrow.

The action of the wind *across* their path is a further cause of the deflection of shot. Long shot suffer more from this cause than round shot—the *lateral* surface of the former being greater,—particularly when the centres of gravity and of figure are not coincident, as the wind, in blowing directly across the path of the shot, will then have a twisting effect upon it. Proper allowance must be made for this deflection, in the aim.

Nearly all elongated shot are made with their fore ends more or less pointed. This appears contrary to the received notions of the effect of the resistance of the air, and is to be regarded rather in the light of a

vulgar error. It was proved by experiments made with the whirling machine, constructed by Dr. Hutton, that the sharp ends of solids of equal diameter, suffered somewhat more resistance than their hemispherical ends, and if the ends were flat, they encountered more than double the resistance. The resistance on the base of the hemisphere to that on the convex side, being nearly as 2·4 to 1: whilst the resistance on the base of the cone is to that on the vertex nearly as 2·3 to 1. (Hutton, Tract 36, *Experiments with the Whirling Machine.)*

Now the retarding effect of the air upon a shot depends more upon the weight or density of the shot than upon its form, its diameter remaining the same; if therefore the resistance offered by the hemisphere is very nearly the same as, or (which is doubtful) even somewhat more than, that offered by the form called the curve of least resistance, the superior weight of the hemispherical end, in shot of equal length, would cause the retarding force of the air to have less effect upon it, and also place the centre of gravity more forward.

During my experiments I found also that round-headed projectiles penetrated iron plates with greater facility than those of which the ends were pointed.

The construction of the fore end of a long projectile, provided it be smooth and convex, is of little moment compared with that of the part which lies behind its centre of gravity; for on the latter mostly depends its

stability, and the steadiness of its flight; for instance, a shot which tapers to the hind part will usually have an unsteady flight. This point is of more consequence with iron than with compound shot, on account of the liability of the former to acquire an unsteady motion on quitting the gun—from the windage.

Though, doubtless, the forms of projectiles will undergo many modifications in order to adapt them to the different requirements of war, still they must essentially resemble each other, since, for practical purposes, there is little to be learnt respecting the general laws which govern the flight of shot, notwithstanding that the theory of the resistance of the air has been found so difficult of complete solution. Hitherto no shot or shell of an elongated form has been found for cannon, of such acknowledged superiority as to cause it to be adopted into the service; for, unfortunately, the projectiles with which the best effect is to be obtained, do not appear well adapted for practical purposes, being invariably those which are compounded of lead and iron. The question, therefore, for consideration is, whether greater range, precision of fire, and facility of loading, do or do not counterbalance the disadvantages attending their use.

The comparative advantages to be derived from the employment of elongated projectiles, whether compound or of iron, are much more prominent in using shells than solid shot, on account of the small velocity which only can be given to them; for although the full

range of a solid long shot will always exceed that of a round shot of the same weight, their comparative force of impact depends upon their velocity. Thus, when the distance between the gun and the object to be struck is lessened, the comparative effect of the round shot is greater, owing to its superior initial velocity; so that at a very short distance from the muzzle of the gun, a round shot will have a greater force of impact than perhaps any other of the same weight of whatever form—the range of a shot is no criterion of its force of impact at short distances. To attempt to give to any kind of elongated shot an initial velocity at all approaching that with which spherical shot are fired, putting aside any other consideration, would entail the employment of very heavy guns, and thus the advantages to be gained by their use would be half destroyed.

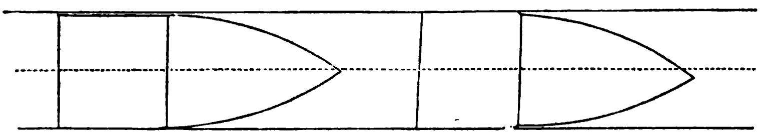
The projectile with which the greatest effect is attainable with rifled cannon, is clearly a *shell* of as great a weight, in proportion to its diameter, as possible. With the view of obtaining a shell in which should be combined all the necessary qualifications in a manner adapted for practical use, I made numerous experiments; but of the many different kinds (numbering more than sixty) of projectiles which were tried during these experiments, there were but three or four which gave perfectly satisfactory results. The projectiles represented in Plate 5 and at page 93, are those which appeared to possess the best combination of iron and

lead, for use with guns to be loaded at the muzzle. Others, which answered very well in other respects, had too much lead in their composition to be of much practical use, on account of the expense of construction, and want of solidity and bursting power.

In Plate 5, Fig. 2 is a longitudinal section, and Fig. 3 an external view of the shell, the firing of which was attended first with success. It is in this instance three diameters long, but may be made longer or shorter. A is the body of the shell (of cast iron); B an iron ferrule or ring, which is sufficiently loose to be moved up or down the body of the shell with facility. C is a ring of lead cast on to the shell, and dovetailed on the body in two or three places. D is another ring of lead, or other suitable metal, also cast on to the body of the shell. The hinder part of the shell is formed in the manner shown in the engraving, with the view of throwing the centre of gravity as far forward as possible, and also to permit the *sabot* which is used with it to be driven up in a straight direction.

The principal feature in this shell is the ferrule or iron ring, the purpose of which I will explain. In making experiments with long shot I found a difficulty (especially when they were more than two diameters in length) in procuring with them an expansion sufficiently *even* to cause their axis to coincide with the axis of the bore of the gun, unless by adopting means unsuitable for practical purposes. The figure to the left (in the accompanying diagram) represents the position,

before the discharge, of a shot with an expanding ring upon the hinder end only. The one on the right hand represents the position which the same shot frequently assumes after the discharge.



The lead after the discharge always appeared to have an inclination in the direction of that part which does not impinge on the bore of the gun; so that if placed on its base after it had been fired, the shot nearly always had an inclination to one side, as seen in the woodcut above. The effects of windage are aggravated with expanding shot, if the gun is rifled in such a manner that one of the grooves (especially if they are broad) at the breech end happens to come at the lower part of the bore, so that the shot will *lie in it*, as this causes an irregularity in the windage.

It was obvious that to ensure an *even* expansion with shot exceeding the length just mentioned—even with the smallest windage possible—they should be made to expand at *two* points in their length, as nearly as possible at the same moment.

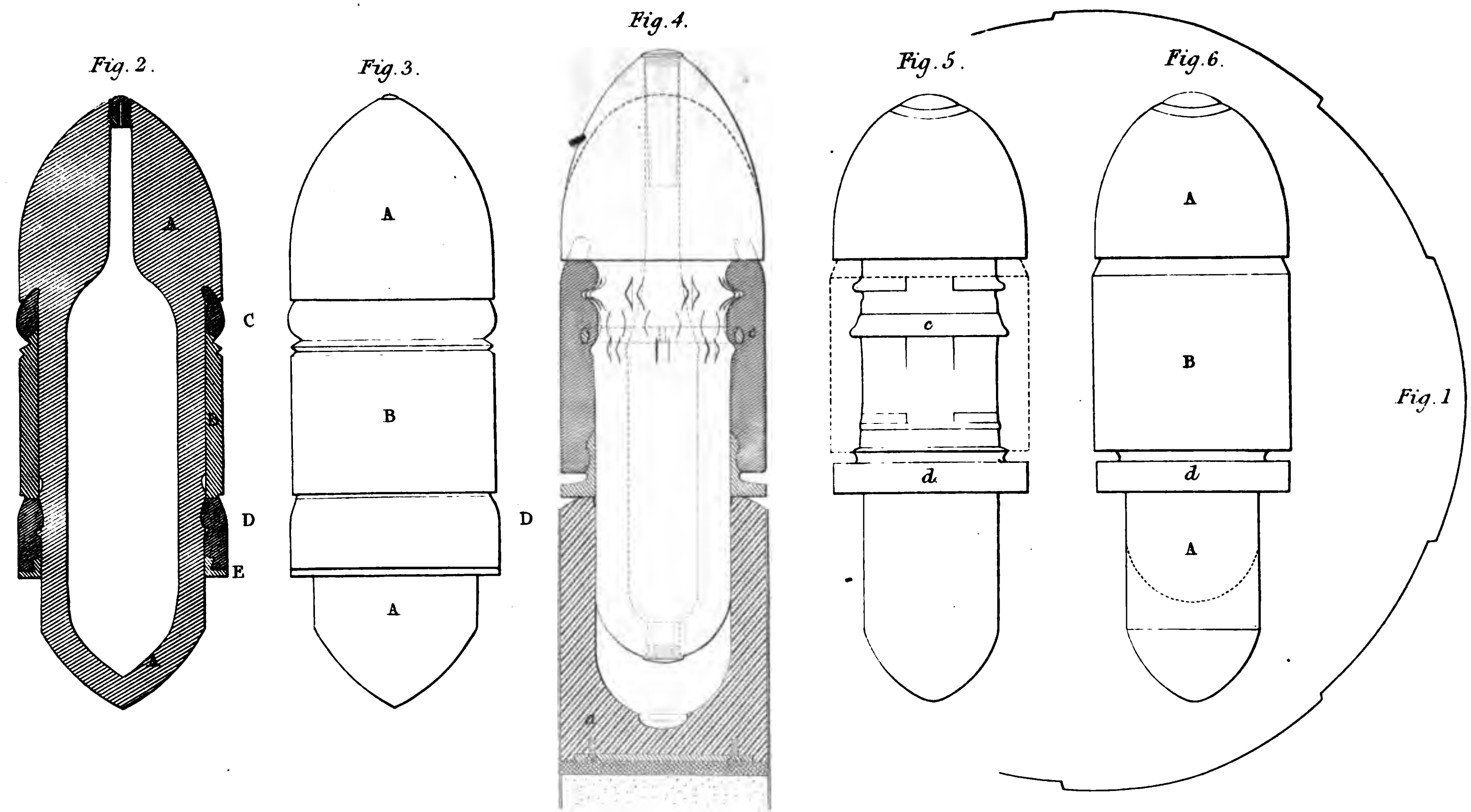
After many attempts I succeeded in effecting this object by means of the ferrule, B, which acts in the following manner:—Upon the explosion of the powder, the lower ring, D, is caused to expand and fill the grooves, by means of a wooden *sabot*, and at the same

moment is driven, together with the iron ring, B, in a forward direction; the latter acting upon the top ring, C, causes it to expand sufficiently to fill the bore, thereby occasioning a simultaneous expansion at two points. The first effect, therefore, of the explosion of the powder upon the shot is to force its axis to coincide with the axis of the bore; it then drives it out in a perfectly straight direction. The bottom ring, E, which is of iron or gun-metal, serves both to protect the lead and to promote its expansion; when the windage is large, the lead upon these shells must be increased in proportion. Figs. 10 and 11, Plate 3, represent the shell as it lies in the bore, before and after the explosion of the powder.

The loading with this shell is a simple and easy operation. The expansion, taking place at two points, also allows of the use of a much less quantity of lead than would otherwise be necessary for shot or shells of such a length, and, consequently, the friction in the gun is considerably diminished. There is no difficulty attending the manufacture of the shell, though that is a point which should not be so much considered as the simplicity in its use.

Figs. 5 and 6, Plate 5, are different elevations of a shell of somewhat similar form to that represented by Figs. 2 and 3, but differing from the latter in the method by which the expansion is obtained, and in the arrangement of the rings. In Figs. 5 and 6, the lead, B, is all of one piece, and the iron ring, *d*, is placed at the

Plate 5.



Experimental Shells.

J.W. Lowry sc.

hinder part instead of at the centre; there is also a smaller ring of iron, *c*, enclosed in the lead, which equalizes the expansion, and permits it to take place at two points almost simultaneously. The whole is so arranged, that the expansion (which can be regulated according to the windage) merely fills the grooves, and thus prevents more friction than is absolutely unavoidable.

The lead which receives the impression of the grooves being situated immediately around the centre of gravity of the shell, less force is required to give the projectile the rotary motion in the gun. When the whole of the lead is placed at the hinder part of a compound shot, the friction is in proportion to the force exerted upon the lead by the powder; and when a considerable quantity of powder is used, as with cannon, the lead is liable also, in consequence of the great heat and compression exerted upon it, to melt or be otherwise injured. An excess of friction is provided against in the shells which I have described, by the above arrangement, which only allows of a given expansion, whilst the lead is secured from injury by the iron rings, which serve as a protection to it both in transporting the shells and when they are fired. The instantaneous expansion of these shells was proved by shortening the barrel of a gun to such a length that, when loaded, the fore end of the shell was nearly on a level with the muzzle of the gun.

These projectiles may be used with or without the

wooden *sabot*, but in the latter case the diameter of the hinder end of the projectile must not exceed two-thirds that of the iron ring, so that the area of the base of the shot shall be less than the area of the base of the ring.

If these proportions are not observed the shell will be driven out without expanding at all, as the expansion takes place before the inertia of the iron body of the shot is overcome.* When the diameter of the shell is greatly increased, the length from the base of the ring to the lower end of the shell—if used without the *sabot*—should be reduced as shown by the dotted lines in Fig. 6.

The weight of these shells when three diameters long and empty, is about three and a half times that of a solid shot of the same diameter. The bursting charge for a shell of this kind, of 32 lbs. weight, is about 1 lb.

Some of these projectiles, 4·2 inches in diameter

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* It would be well to pay attention to this point in musket bullets which are used with a cup or plug—for it is evident that the efficiency of the plug must depend materially upon the size of its base, as compared with the whole diameter of the bullet. To produce a proper effect, the area of the base of the plug should be fully two-thirds that of the bullet; the larger the base of the plug the greater will be the expansion, but when it exceeds the size abovementioned, care must be taken so to secure it that it will not be driven through the bullet, which is likely to happen if the plug be placed loosely in it.

and of about 32 lbs. in weight, were fired with very good effect at Shoeburyness, in May 1858. The gun used on this occasion was a 32-Pr. brass howitzer block, bored to the size of a 9-Pr., the bore (which was rifled with a turn of 11 feet), being 5 feet in length only. No wooden *sabot* was used in this instance, and the windage was small, —·035 in. only. With an elevation of 5°, and a charge of 4 lbs. of powder, these shells attained a range of nearly 2,000 yards: the average deflection being about 10 yards, in each case to the right of the line of fire.

The gun had the usual notched sight, the correctness of which had not been tested by any previous trial; it is, therefore, impossible to say how much of the deflection was to be attributed to the actual deviation in the direction of the turn of the grooves which is peculiar to all rifled projectiles, (for which no allowance was, in this instance, made,) or how much of it arose from other causes; the *recoil* also (owing to the lightness of the gun—20 cwt. only) was considerable. The *difference* in the deflection of these projectiles was, however, very small.

Fig. 4 is a modification of Figs. 5 and 6, the body of the shell,—represented in elevation,—is cast in one piece; and the upper ring, *c*, (of wrought iron,) is of a different form, and fits more loosely. The action of these rings is very peculiar; they are driven up with the lead, (which, with the rest of the figure is represented in

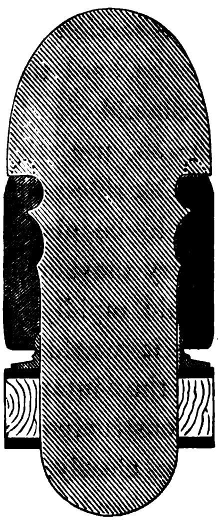
section,) until they are stopped by the projections on the body of the shell, thereby causing a corresponding expansion at that part of the projectile, and equalizing the action of the lead. In many cases the double expansion caused by the upper and lower rings is distinctly visible upon the exterior surface of the lead. These rings should be carefully placed in their proper position on the body of the shell before the lead is cast on them. *a*, is the wooden *sabot*, which should be of oak or other hard wood, and slightly bevelled at the top, or the part which touches the bottom of the lower ring; at the bottom of the *sabot* is a thin iron plate, and over the plate a piece of thick felt. This shell is better adapted for use when a large windage is necessary. A smaller quantity of lead may be used with these shells when the *sabot* is employed than when it is not.

There are several other points connected with these projectiles, which it is not necessary to enter into here, my object being merely to give a general idea of the principles of their construction.

The shells represented in Fig. 4 are extremely effective; some were fired at Shoeburyness, on the 24th of February, 1859, from the 32-Pr. howitzer before mentioned; the shells (empty) weighing rather less than 32 lbs., the windage being as much as ·08 in.; the charge of powder was 4 lbs. 2 oz., and the elevation of the gun 10°. On this occasion a range of over 4,000 yards was attained; the average deflection,—as compared with those mentioned at page 91—being about

proportionate to the elevation. Considering that with

Fig. 1.



the same elevation the Service 32-Pr. howitzer throws a shell of 20 lbs. weight to a distance of 1,900 yards only, this is, perhaps, the greatest comparative effect that has as yet been obtained with a rifled gun; with an elevation of between 30° and 40°, the range would probably be not far short of 10,000 yards.*

Fig. 1 in the woodcut, represents a solid shot on the same principle; but as no bursting charge is required in this case, the hinder part of the shot may be reduced in diameter, and the shot fired without the sabot which is employed with the others; but as it is advisable—especially with large guns—to have as little space as possible between the charge of powder and the lower ring, and as it is objectionable to have the hinder ring heavier than is necessary, an

* There is a most remarkable circumstance attending the flight of these projectiles, which is, that when fired with equal initial velocities, but different elevations, their ranges appear to vary in a degree as great as, or even greater than they would if the projectiles were fired in vacuum; when their ranges are supposed to vary as the sine of twice the given elevation.

additional ring of wood, may be used with advantage.

Fig. 2.

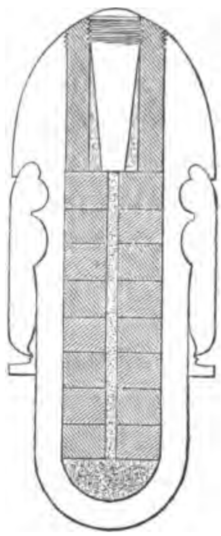


Fig. 2 represents a longitudinal, and Fig. 3 a transverse section of a projectile which may be used as a Shrapnell shell. Should it be considered desirable to use this description of shell with rifle guns, no loose bullets should be placed inside it, or the rotary movement of the projectile would rapidly be impaired; therefore, it would be necessary to have the internal portion of the shell constructed in separate pieces fitting closely together, a small space being left for the bursting composition.*

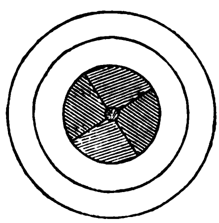


Fig. 3.

No attempt should be made with compound shot or shells to cause the lead to expand entirely in a *lateral*, or outward direction; for although a slight tendency that way is almost necessary when the windage is very large, yet the lead should chiefly be made to expand by being driven forward, or up, in a straight direc-

* It was only after some hesitation that I allowed the above woodcut to be inserted, on account of a certain resemblance which it has in some respects to a shell of Sir W. Armstrong's invention,

tion, and thus be made to fill the grooves by the compression which the sudden action of the powder effects upon the soft material, and which takes place before the inertia of the whole body is overcome. If the lead be made to expand in a lateral direction only, it is compressed between the body of the shot and the gun, and either the shot strips, or the lead is torn from the shot and blown out of the gun in fragments. On the other hand an imperfect or insufficient expansion,—independently of other disadvantages,—fouls and leads a gun extremely.

It will be found that the shells of which I have just given a description, combine all the qualifications which have been set forth as requisite; and they will, at least, serve to illustrate one or two practical methods upon which rifle shot for cannon may be constructed.

There is an objection to the use of long iron shells, which I have not yet mentioned—a liability, especially when made of *cast* iron, to break in the gun.

An iron shell of small diameter, although greatly elongated may, without injury, be fired with considerable velocity, because the entirety of the small mass is immediately affected by the charge of powder; but a large shell of this description cannot, from its massive-

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but as I sent a drawing of the above shell to the Ordnance Select Committee, at Woolwich, a long time before I was aware that Sir W. Armstrong made use of a shell of somewhat similar internal arrangements, I have allowed it to remain, with this explanation.

ness, have suddenly imparted to it with safety a like velocity.*

The comparatively small portion of the surface of the shot, which is immediately acted upon by the initial force produced by the explosion and the velocity of expansion of a large charge of powder, will therefore render the shell, from its brittle nature, very liable to break. When to this is added the irregular movement of an iron projectile from the existence of windage, and the friction it experiences in its first contact with, and in traversing the grooves, this objection to the use of large iron shot, at least for horizontal firing, becomes important. A good *compound* shell, even when used on a large scale, would be preferable, as the compressibility of the lead will allow the inertia to be more gradually overcome.

A *wrought* iron solid shot, or a shell even (if it were not hollowed out too much) might be used of a greater length than one of cast iron, supposing that such a projectile were required for penetrating iron plates, or for service of that description. Compound shots or shells might also be constructed (the

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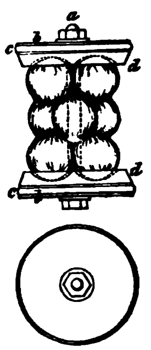
* From some recent experiments which I have made, (an account of which will be found in the Article on Gunpowder,) I have reason also to believe that, with proportionate charges of powder, the initial force of the charge actually *increases* with the calibre, and in a very high ratio.

iron part, at least) of wrought iron of the toughest and hardest kind, for the same purpose. In fact, there is no result obtainable with iron projectiles, which may not be had in a higher degree with those of a compound make. The only real advantage which the former possess, consists in their homogeneity.

Were it required to use grape shot with rifled cannon, several plans might be devised for doing so without injuring the grooves, and probably even to render such an application advantageous. The accompanying woodcut shows one method of accomplishing this:—*d d* are two thick circular plates of brass or gun metal, hollowed out on the side next the shot. Between these plates the shot are placed; *c c*, are two circular leaden plates, slightly rounded at the edge, so as to project a little beyond the thick gun metal plates. Beyond these are placed two thin iron plates, *b b*.* The whole is traversed by an iron rod, *a*, and tightened together by means of a nut at one end of the rod. A layer of felt might be used instead of lead, so that, even supposing no advantage to be gained by the rifling, no injury would happen to the grooves, as the pres-



* The top plate might be made of a hemispherical form, if thought expedient, and not too heavy; or another tier of shot might be added.

sure of the discharge at one end, and the resistance of the air at the other, would cause the lead or felt to be compressed in such a manner as to fill the bore, without allowing the iron plates to impinge on it at all.

An elongated shot of lead, hardened or pointed with iron, fired from a rifled cannon,—the polygonal bore would be well adapted for this kind of shot,—would prove a very destructive missile. The concussion produced by the impact of such a shot, would be very great on account of its small elasticity. The effect of such a projectile has yet to be witnessed, but I think there is little doubt that it would prove more effective, even against stone walls, than iron shot.

A 95 cwt. 8-inch gun, bored to a 6-inch, could be used for this purpose; such a gun, with a turn of 24 feet, would throw a shot of the above kind, of similar form to the Enfield bullet, and of about one cwt., with great effect, as to range and accuracy, as well as impact.

Solid elongated shot of pure lead—of which I have fired several varying from 20 lb. to 40 lb. weight—are too *soft* for cannon shot; with only a moderate windage, they *lead* the inside of the bore extremely; in consequence of this they require to be hardened. As it is difficult, however, to obtain a sufficiently quick expansion with such shot when much windage is allowed, they should be made of a form corresponding to the bore of the gun.

The practice, with all rifled guns which fire expanding projectiles, will become impaired if the guns are not occasionally washed out after being discharged; otherwise the residue of the powder from the previous discharges—which is never completely driven out by the shot, but is accumulated and hardened by each fresh discharge—will foul the gun very rapidly, especially in hot or dry weather.

The track described by elongated projectiles, approximates more nearly than that of spherical shot, to the curve of a parabola. This is accounted for by the weight of the former class of projectiles being so much greater, as compared with the resistance of the air upon them, than is the case with spherical shot; so that the resistance of the air has comparatively less effect in reducing their velocity.*

The result is, that elongated projectiles will achieve

* Figs. 5 and 6, Plate 4, are intended to give an illustration of the flights of a round and an elongated shot respectively, more, however, as a representation of the different curve of the tracks described by the two kinds of shot, than of their relative ranges. The round shot is supposed to be fired with the ordinary, and the long shot with a lower, velocity. I should also remark that the curves shown in Figs. 1, 2, 3, and 4, are represented as being the same in each case, whereas they would in fact differ very nearly as much as those represented in Figs. 5 and 6; but as they are only intended to draw the reader's attention to the effects produced by an alteration of the position of the centre of gravity in the shot, I did not consider it necessary to attempt to define the relative curves described by each.

greater accuracy at long ranges or when fired at great elevations.

With gun carriages for land service, as at present constructed, a great elevation cannot conveniently be obtained. In order to remedy this, I would suggest that a joint be made in the trail, as shown in the carriage of the 32-Pr. rifled gun in the frontispiece, so that by means of an endless screw the gun may be elevated or lowered. I have already applied this method to a gun carriage, on which a 28 cwt. gun was mounted, and it appeared to be capable of standing the effect of the recoil very well. The dotted figure in the plate represents the highest elevation attainable with the ordinary gun carriage; the other figure represents the gun at an elevation of 45°, to which it may be elevated by means of the joint in the trail. This might also be made use of in attacking troops posted on heights. The smaller figure in the frontispiece is a sectional view of the joint, showing the manner in which it works. No elevating screw need be employed at all with this joint; and trunnions might also be dispensed with.* An iron pin (*a*) connects the two parts of the trail, and prevents any strain upon the screw, when transporting the gun.

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* See the figure, representing a rifled cannon and carriage constructed in this manner, upon the cover of the book.

ON THE GROOVES AND THE INCREASING SPIRAL.

THE point which next claims our attention has reference to the description of *groove* best calculated to give the requisite angular velocity to the projectile.

This will depend, altogether, upon the character of the shot employed, *i.e.* whether it is made of iron, or of a compound of iron and lead.

The great mistake which has prevailed in all attempts hitherto made to effect improvements in rifled cannon, appears to be that—in order to adapt them for *iron* shot —the mere form of the groove has almost solely occupied attention, without a due consideration to the alteration in the turn rendered necessary by the different effects of the resistance of the air upon shot of different *sizes.* But although so much attention has been paid to this point, the form of groove best adapted for iron projectiles has not yet been satisfactorily determined.

Were the difference between rifled small arms and cannon merely in the metal used for the projectiles,

the form of groove would, I grant, be the chief point to be considered; but as the groove can only be looked upon as the means whereby a shot receives its rotary impulse during its passage through the gun, so any variation in its form is to be regarded only in so far as it produces more or less friction in accomplishing this object. Thus, in comparing the merits of different shaped grooves, whether they be triangular, as in the case of Mr. Whitworth's gun, circular, as in Col. Jacob's and others, or such as are formed by the oval bore of the Lancaster gun, the amount of friction is the chief matter for consideration; and that gun will be found to have the advantage, in respect to the point now under discussion, which has its grooves so constructed as to produce the least and most equal amount of friction. Of these forms of bore, however, the Lancaster, although perhaps a good form for leaden bullets, must be considered as the least suitable for cannon, on account of the irregularity of its action, being frequently the cause of friction so great as to occasion the bursting of the gun.

In Plate 2, Figs. 1, 2, and 3, are elevations of the different shells fired from these guns, and under each elevation the form which the bore of the gun assumes. Fig. 1 is Whitworth's projectile (bore 4 2 inches); Fig. 2, Jacob's (proposed width of bore, 4·2 inches); and Fig. 3, Lancaster's (bore 8 inches). These shells are all on the same principle—each shell has projections corresponding to the grooves in the gun; the difference is merely in the *form* of groove, very little attempt being

made with either to alleviate the effects produced by the necessary windage and the sharpness of the angle of the turn peculiar to cannon from which iron projectiles are to be fired, These, however, are most important matters for consideration; since the friction produced by the passing of the iron shell out of the bore, as I have before observed, is not, as with expanding shells, equally distributed over the *whole* of the interior surface of the mortar, but takes place at certain points only.

In the employmont of iron shells these matters will therefore be the subject of many experiments before any degree of perfection is attained. Great nicety will also be required in the construction of the shells, for although nearly the utmost limit of the range possible of attainment with elongated shot may, before long, be acquired, the *accuracy* of their fire (especially that of iron shells) will always be open to improvement.

The hexagonal form of bore, or angular groove, appears to meet with some favour; but although this form may be well adapted to small arms with which unusually long bullets are used, and which therefore require a great turn, it does not appear to be altogether the best form for ordnance used for firing iron projectiles.

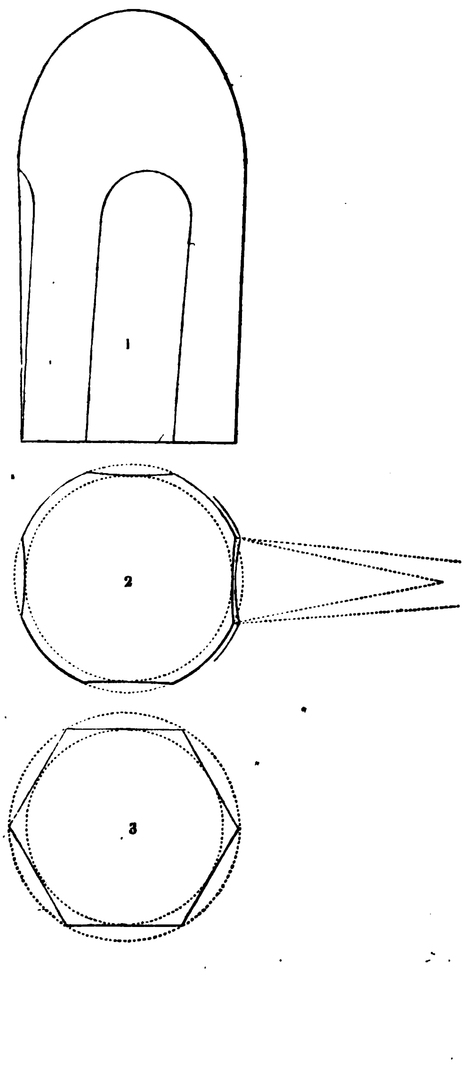
The object of the hexagonal form of bore is perfectly intelligible when the friction, as with expanding shot, is distributed over the whole interior surface of the bore, as this form gives the bullet a firm hold of the grooves;

but with iron shot that is impossible; and therefore the angular projections on the shot will not be productive of less friction than those of another form, and are not otherwise peculiarly effective, as they, in common with all other kinds of projections upon iron shot, can impinge on the bore at one or at two points only of its surface.

This form of projectile may perhaps be considered to possess an advantage over some others, where a great turn is used, on account of its *strength*, but for no other reason that I can discover. If this particular form of groove is attended with any advantage, a figure of more sides than a hexagon would be preferable—provided that the shot have a sufficient hold on the grooves—for the nearer the perimeter of the shot approaches a circle, the smaller will be the friction which it will suffer in passing through the air (Figs. 2 and 3, page 103, will exemplify this). The friction caused by the shot passing along the bore will also be more equally distributed, and consequently the latter will be subject to less wear.

The number of grooves, or of sides, should depend upon the size of the bore of the gun; for supposing the windage to be nearly the same for each gun, it would be smaller in proportion to the whole diameter for a gun with a large than for one with a small bore: for instance, if it were found that for a 9-pounder bore (4·2 inches) the grooves should not be more than six in number, or that a *hexagon* would be the best form;

for a 68-pounder (8·12 in.), a shot of an octagonal form, or of a figure having a greater number of sides, would have as firm a hold on the grooves as a shot of a hexagonal form would have on the grooves of a gun having a bore of four inches only.



The friction would be considerably reduced if the alternate sides of the octagon were rounded in the manner shown at Fig. 2 in the accompanying woodcut; and if at certain points of their surface they could be made to impinge more readily than at others on the surface of the bore, a nearer approach to coincidence between the axis of the bore and the longer axis of the shot would result,

and a truer flight for the projectile thus be obtained. In Fig. 2 is shown a method of accomplishing this, by constructing the shot and gun in such a manner that the four sides of the shot, instead of being flat, shall be arcs of circles, the corresponding curves in the bore being formed by arcs of a circle of a much smaller radius than that which forms the curve of the *shot*. In this way the shot can only come in contact with the bore at four points, and would therefore be driven out in a tolerably straight direction, and greater accuracy would thus be obtained. This method might, at least, be used with mortars of large calibre and breech-loading guns, if not with others. Fig. 1 is an elevation of the projectile which would be used with a large gun or mortar upon the above principle. Cast-iron shells for rifled guns, of large calibre, should not exceed two diameters in length; otherwise they will be liable to be broken or to burst the gun; a consequence resulting as much from the strain to which they are subjected before their inertia is overcome, as from the greater turn which it is necessary to employ with them.

The great turn required for iron projectiles, is attended with the solitary advantage that it tends to bring a larger number of the projections in contact with the grooves, so that the friction is more distributed, and the axis of the projectile is brought to coincide more nearly with that of the bore than would be be the case if a slight turn only were used.

Iron projectiles appear better adapted for mortar

practice, than for horizontal firing. Independently of the comparative shortness of the bore of a mortar, and the low velocities given to the shells, they have the advantage of always being fired with the same elevation; so that being fired always under the same circumstances, practice would enable artillery officers to discover, and so to make a proper allowance for, the deviation and other defects which arise from the windage. Although neither the same range nor accuracy could be obtained with iron as with compound shells, still, a considerable improvement in both the range and accuracy of iron shells could be made, if a little attention were devoted to the subject; they might be made at least to possess certain advantages over spherical shells.

For the better ascertaining the movements of iron projectiles when passing out of the gun, and the effects produced by projectiles and grooves of different forms, I would suggest a simple experiment. Take two or three cylinders of iron, gun metal, or even hard wood, not less than 3 feet in length, and 8 or 9 inches in diameter, so that when hollowed out, the bores would be at least 5 or 6 inches in diameter. Have them bored and rifled, each in a manner corresponding to the form of the shell with which it is desired to make an experiment. Let each shell be then passed through its cylinder with various degrees of velocity, the cylinders being placed at different inclinations. The effect which would be produced by a greater or

less velocity, or by a higher or lower elevation, and, indeed, all the different circumstances attending the passage of the shot out of the gun might thus be clearly seen; and on the whole, by this simple and inexpensive experiment, a better idea might perhaps be formed of the comparative effects produced in the gun by projectiles and grooves of various forms, than could be acquired by actually firing the projectiles from a gun. The irregularity of the friction consequent upon the windage, gives rise to the chief *mechanical* difficulty in the way of all attempts at improvement in these matters. This difficulty would, however, be considerably alleviated, were a better knowledge of the subject to guide the employment of the mechanical means brought to bear upon it.

The form of the grooves for compound shot—the friction being distributed over the *whole* surface of the bore—is not a matter of so much moment as with iron shot. A sufficient number of experiments have not yet been made to establish the superiority of any particular form and number of grooves for rifled cannon employed for this kind of projectiles. It appears, however, to be generally admitted, that the shallower and the fewer they are in number, the less is the friction, and I would certainly advocate the use of three only, were the angle of the turn the same as in an ordinary rifle; but as this is not the case, and as that portion of the shot which enters the groove is, in the case of cannon shot, smaller in proportion to its

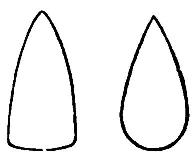
size than with a leaden bullet, I think it preferable to use a greater number, proportionate to the size of the bore. In the 32-Pr. howitzer, mentioned at page 90, which is rifled upon my principle, there are five grooves, rather broader than the bearings, and one-thirty-second part of an inch in depth, but going off about one-sixty-fourth part of an inch deeper towards the centre, and having the edges slightly inclined inwards, as shown full size in Fig. 1, Plate 5. The angles on that side of the grooves against which the projectile bears on entering the gun should (in guns of large calibre) be slightly rounded off, to prevent any abrasion of the lead on the projectile, when loading.

Armstrong's gun has a great number of grooves, but the circumstances under which the shot is fired are unusual, the gun loading at the breech, and the shot, which is larger in diameter than the bore, being forced through it, so that it is *compressed*, instead of being *expanded*.

A considerable number of experiments will yet have to be made upon this subject, as it materially affects the range and accuracy of the shot, though more in the case of iron, than of compound shot.

I should not have considered it necessary to notice the principle of the *increasing spiral* (which is employed chiefly by the Americans), but for several attempts that have been made to use it for iron projectiles. Whatever advantage or disadvantage attends this mode of rifling with *small arms* would appear to resolve itself

entirely into a question of the friction of the bullet's passage out of the gun, as the bullet must ultimately acquire a velocity of rotation corresponding to the last turn given to it before quitting the piece. With long iron shot, however, the application of the increasing spiral is positively detrimental. The friction increases at that part of the gun where the shot acquires nearly its greatest velocity—a part where friction should be most carefully avoided, for there it is most likely to cause a fracture either of the projectile or the gun. If this kind of turn be attended with any advantage at all, it can only be when employed either for the American flat or round ended



picket (*see* woodcuts), or the ordinary spherical bullet.

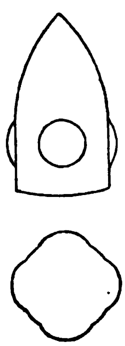
With long shot, of any other kind than the above, the use of the increasing spiral must be utterly and at once condemned. It must not only increase the friction, but as the form of the grooves actually changes, it must also render the shot particularly liable to shift its position, to strip, or to break. I consider, therefore, that to have the grooves formed of an *equal* spiral conduces not only to the avoidance of much friction, but also to the attainment of greater precision.

It appears strange that no one (to my knowledge), has observed the impossibility of a *perfect coincidence* existing between the sides of a groove cut on the principle of the increasing spiral, or gaining twist.

If the sides be made equidistant, the form of the groove will change; and the change will be still greater if the sides be not equidistant, as they cannot then be parallel to each other.

Grooves cut with a regular spiral may be described as *straight lines* applied to a cylinder; whilst those which form an increasing spiral are represented as *arcs of circles*, or other curves. If two concentric arcs of a circle be described on the interior surface of a cylinder, the distances between points taken at right angles to the axis of the cylinder will vary.

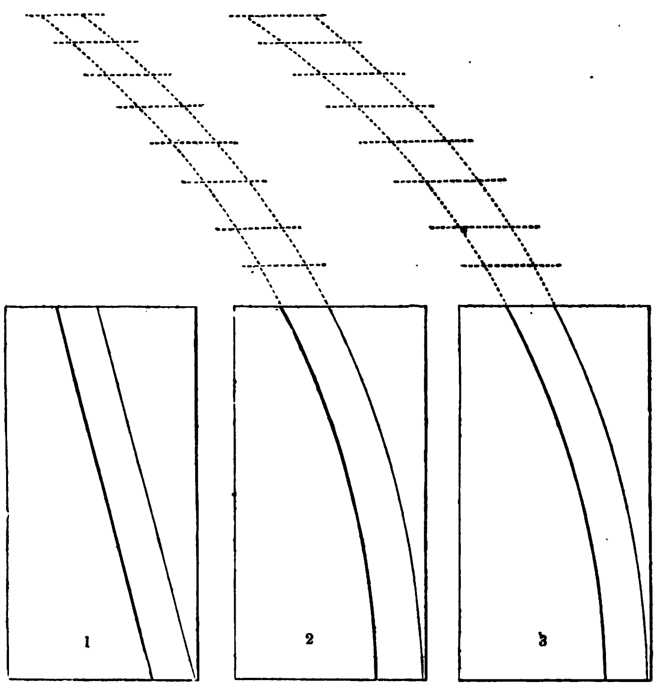
When the grooves are cut with an increasing spiral, a little reflection will show that any projection on the bullet which fits exactly into the groove at the one end cannot do so at the other; with the single exception, when the projections are hemispheres, or other portions of spheres, (*see* woodcut,) and the sides of the grooves are equidistant throughout (as in Fig. 3, page 110); when in fact, the groove forms what is called by mathematicians a *tubular* surface. When the projection, supposed of iron, has any *length*, it must either fit so loosely at the breech as to cause a great windage, or so tightly at the muzzle as to strain the gun unduly, and cause it to burst; as was frequently the case with the Lancaster gun, which has an increasing spiral.



The following cuts are intended to represent the defects of the increasing spiral.

Figures 1, 2, and 3, show three cylinders laid open. Fig. 1, represents a groove forming a regular spiral. Fig. 2, a groove with an increasing spiral, the curves being formed by arcs of circles of the *same* radius.

Fig. 3 shows also a groove with an increasing spiral,



the sides of which are formed by arcs parallel one to the other, so that the radius of one will be *less* than that of the other. Here it will be seen that the grooves on the principle of the increasing spiral cannot be true, for it is only by making the sides of the grooves parallel to each other (Fig. 3), in the direction of their

common centre, that the grooves can maintain the same width throughout, in which case they are not equidistant in a direction at right angles with the bore; and if the sides are equidistant in a direction at right angles with the bore, as in Fig. 2, they are not parallel, but continually approach each other. In the former case the grooves widen, and in the latter they contract in the direction of the muzzle of the gun. The intended longitudinal increase of the turn of the groove, therefore, is not the only alteration which takes place. It is evident, as I have shown, that other very undesirable changes attend this description of groove. There can be no doubt that the bursting of the Lancaster gun, not to mention the failure of others, is in a great measure attributable to the defects inherent in this rifling on the principle of a "gaining twist." Although these defects may be almost imperceptible in small arms, yet the irregularities which attend this method must be very sensible when it is applied to guns of large calibre. These defects are also not noticed with small arms, because the bullet being made of lead instead of iron, accommodates its form to the varying shape of the grooves in its passage along the barrel; but it is clear that the friction resulting from this must be very prejudicial.

Many points to which attention has here been particularly drawn, may possibly appear trivial to those who have not paid much attention to the subject. But these trifles make in the aggregate the total effect of

the projectile, and all who *have* studied the subject, and followed it up by experiments themselves, must be well aware of the difference in the shooting of a rifled gun, which will sometimes be caused by, apparently, the most trifling alteration. There are few things which require so perfect a combination of qualities, in order to arrive at excellence, as rifled artillery; and, considering its importance, nothing should be neglected which may tend in any way to ensure it.

ON THE COMPARATIVE ADVANTAGES ATTENDING THE EMPLOYMENT OF RIFLED AND SMOOTH-BORED GUNS.

By taking all the foregoing circumstances into consideration, we may judge of the advantages and disadvantages arising from the employment of elongated projectiles. The former appear principally to consist,—firstly, in the great precision with which long shot can be fired; secondly, in the high velocities sustained by them at long distances; thirdly, in their superior weight as compared with that of the gun from which they are fired; and, fourthly, in the certainty of their explosion (when used as shells) upon striking the object.

On the other hand, the disadvantages attending their use—besides those which must always accompany the employment of rifled cannon, such as the extra expense in their construction, the carriage of the shot, and so forth—lie chiefly in the comparatively low initial velocities to which they are circumscribed, and also in the fact that their *ricochet* is so irregular, that

beyond the first graze no dependence is to be placed upon them; they invariably bound off in the direction of the turn, in such a manner that the track of a shot, after the first graze, appears sometimes to describe nearly a semicircle.

To form a proper estimate of the results attainable with rifled cannon, they should be compared with those obtained with smooth-bored guns. I will therefore draw the reader's attention first to the comparative effects produced by elongated and spherical projectiles, when both are constructed entirely of iron, that is to say, non-expanding.

Regarding this question in a practical point of view, we may conclude that the weight of every gun must necessarily have certain limits according to the purposes for which it is required. In forming therefore an estimate of the advantages which might accrue from the application of the rifled bore and elongated shell to cannon, whether light or heavy, it is necessary to bear in mind that, besides the greater accuracy of aim, and certainty of percussion (both of which are rather doubtful with non-expanding shells) the only advantage —with a gun of a given weight—lies in the superior weight and range of the projectile. The first consideration then is the effect which may be produced with a rifled gun of a given weight, adapted for the use of elongated iron shells, as compared with that which would be obtained with a smooth-bored gun of the same dimensions.

As sufficient *data* have been acquired to enable us to form some opinion upon this matter, I propose, in order to show the comparative results which would be obtained by the use of rifled or smooth-bored guns, to take, in the first place, as an instance, the largest solid shot gun used in our service; viz., the 68-pounder cast iron gun. Fired with a charge of 10 or 12 lbs. of powder, and with 5° of elevation, such a gun, if rifled, will throw an elongated iron shell of 100 lbs. weight to a distance of about 2500 yards to its first graze. With the same elevation the smooth-bored gun, fired with a solid shot of 68 lbs. weight, and a charge of 20 lbs. of powder, has a range of 2250 yards to its first graze. Here the advantages, at first sight, appear considerably in favour of the rifled gun; but if we consider certain other circumstances, we find that these advantages are more apparent than real. In the first place, the greatest effective range of the long shot, (when fired with elevations even below 5°,) may be said to be attained at its first graze, as its direction after that is not to be depended upon; whilst the effective range of a round shot is much beyond the distance of its first graze. The actual difference therefore in the effective range is not, even when both guns are fired with tolerably high elevations, always in favour of the long shot. In the second place, the difference in the weight between long shells and round shot is balanced, in a measure, by the power of double shotting the smooth-bored gun in close action

in a naval engagement, or of firing shot with greater velocity when used against fortifications.

The larger bursting charge which an elongated shell will contain, is compensated for, in some measure, by the power, with the smooth-bored gun, of throwing red hot shot and molten iron,* neither of which could be used with the rifled gun.

It is questionable, moreover, whether the accuracy attainable with long iron shells at the longer ranges, when a charge of one-eighth and upwards of the weight of the projectile is used, is sufficiently great for the excess of range to be of any but doubtful advantage. A heavy shell would indeed be worse than useless if it did not hit the mark, as there would be so much the more thrown away. I was informed, on good authority, that the Lancaster guns employed in the Crimea were fired at an expense of

* The advantage to be acquired in naval combats by the substitution of molten iron for red hot shot, appears rather problematical, (unless for exceptional service,) from the danger attending its use. A heavy shot striking, either a vessel containing a quantity of the fluid iron in a state of preparation, or a shell filled with it, during the time of loading, would be attended with very disastrous consequences. The same may be said of all those chemical compounds for destroying the enemy wholesale, the employment of which is occasionally proposed. The effect, however, which would be produced by these compounds, although it sounds very formidable in theory, would be likely to prove, in practice, much more noxious to those employing them than to the enemy.

nearly one hundred pounds a shot. A hit or miss in this case was therefore a matter of no small consideration.

In naval engagements the rifled gun would have a great inferiority, from the slowness with which only they could be served; this would utterly preclude their use as broadside guns. Elongated and spherical projectiles each possess advantages which the other has not; but on the whole we may consider, in this instance, that the balance is rather in favour of the spherical shot and smooth-bored gun. Nearly the same comparative result would occur with guns of every other size; that is to say, with such as are used for horizontal firing.

Elongated iron (*i.e.* non-expanding) shot or shell have so few advantages compared with compound or round shot, that their permanent adoption into the service is very problematical. They might be used for heavy mortars where quick loading and high velocities are not so much required, but their unfitness for horizontal fire is obvious. The full advantages resulting from their special qualifications are, in fact, only to be obtained in their employment at great elevations. This is more apparent as the size of the shot is increased.

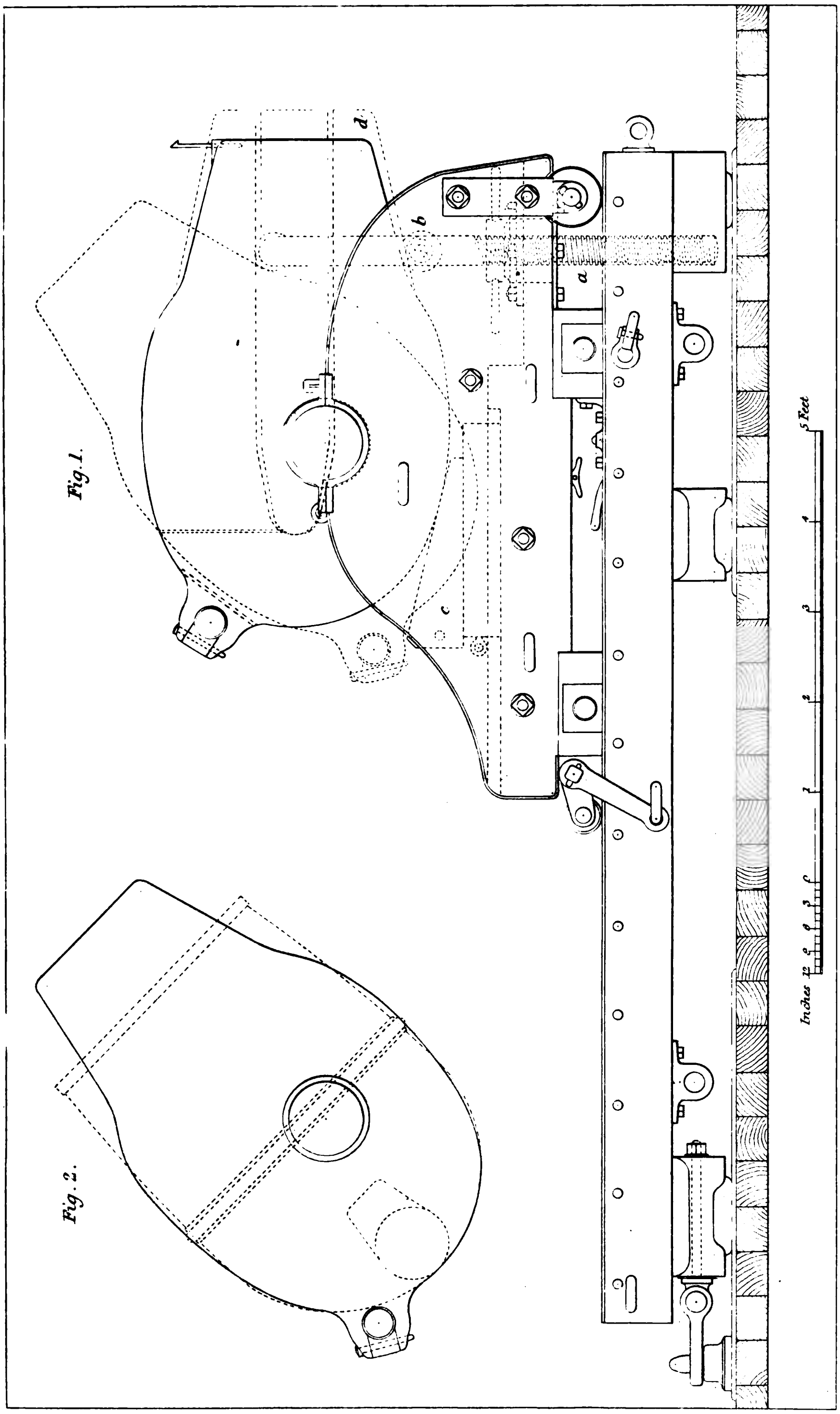
A gun or mortar, of a description similar to the one represented in Plate 6, might be employed for this purpose. It is supposed that the metal used in its construction is cast iron, and the weight limited to that of the heaviest pieces used in actual service; it being also assumed that great general effect—*i.e.* as regards

the weight of the projectile, the velocity which can be given to it without impairing too much its accuracy, the weight of the gun and the economy of its construction—is the object, rather than the most extensive range at low elevations only. To attain the latter with a projectile of equal weight, the gun would of course have to be of greater length and (unless it could be constructed of a stronger and more expensive metal) of greatly increased weight.

The description of gun to which I would at present direct the reader's attention, may be called either a mortar or howitzer, as it could be used as either. It is 5 ft. 5 in. in length only, and rather heaiver than a 10-inch solid shot gun. With a 9 or 10-inch bore (according to the length of the projectile) it will throw a shell of more than 200 lbs. weight, and may be fired with a charge of 20 lbs. of powder. It might be employed equally as a siege gun, or in a mortar vessel. Besides an enormous increase in range, it would, as a mortar, have the advantage in almost every other respect over the ordinary 13-inch mortar, (the weight of which it would not much exceed,*) and could also be used horizontally with very great effect, as it would even then have a greater range than a 10-inch gun, and throw a shell of more than double the weight of a 10-inch spherical shell.

It should have a turn in about 15 feet, in order to

* Fig. 2 in the engraving (Plate 6) shows the respective dimensions of the above gun, and those of a 13-inch mortar.



J.W. Lowry fc.

insure a perfectly steady flight throughout. One peculiar advantage which such a gun would possess over rifled guns generally, as compared with smooth-bored guns which throw shot of equal weight, arises from the fact that the 13-inch mortar being *chambered*, that portion of the shot which receives the first impulse from the powder would be nearly the same in both cases ; and thus one of the chief causes of the bursting of rifled ordnance would be very much lessened.

The projectile, supposing it to be similar to the one shown in the woodcut, page 103, would have a terminal velocity one-half larger than that of a 13-inch spherical shell. This would give it (besides a greatly increased range and force of impact,) a velocity of descent which, supposing it a percussion shell, would considerably increase its power of penetration before explosion. A shell of this kind might be fired with a degree of velocity, which, whilst sufficient to give it an extended range, would allow the resistance of the air upon it to so reduced that it would describe a line of flight more nearly approaching to a parabolic curve than that of spherical shells, even when the latter are fired with lower velocities, and much more nearly so than when they are fired with the ordinary service charge. For this reason, the heavier the description of shell, the higher is the elevation at which an increase in its range can be obtained, and the smaller will be the angle of its descent. When we consider the difference, not only in the curves described in their

flight by round shot of equal sizes, but also the variety of curves described by shot and shell of different sizes when fired with different velocities, (a circumstance which considerably affects the precision of the fire,) the value of these facts will be appreciated.

I am of opinion, also, that the lateral deviation of elongated iron shells, when these projectiles are fired with a velocity no greater than that with which shells are ordinarily projected from mortars, will be found more *uniform* than that of round shells; the elongated shells acquiring a rotary movement about an axis situated always in the same direction, the effect produced by the act of rotation on their flight is likely to show less variation than in the case of round shells, which acquire variable rotary movements about an accidental axis. If this be found correct the elongated would prove superior in every respect to the spherical shell for vertical fire.

The distribution of metal in the piece of ordnance represented in Plate 6, and the general construction of it, are the result both of personal experience and of a careful examination of the different data procurable from practical and scientific sources.

It will be seen, on referring to the engraving, that the gun is elevated at the muzzle by means of a screw and roller (*a* and *b*), so that by shifting the quoin (*c*) at each degree of elevation, the gun is continually supported at three different points. The rest of the carriage is similar to the ordinary gun-carriage used

for the heavy deck guns of a ship. If used with Fergusson's Compressor, the gun might be mounted on a carriage similar to the one shown in the Plate.

It is an important feature in the use of long iron shells that the bore of the piece from which they are propelled may, with advantage, be of small length only, for the velocity with which the best effect is obtained with these shells—the deflection increasing with the velocity in a much greater degree than the range,—can be given with a comparatively short gun, and owing to their own length, they acquire as true a flight as they would have if fired from a gun with a longer bore. The friction in the passage of the projectile out of the gun is also much less when the bore is of reduced length.

The dimensions which I have given for this piece of ordnance would have to be considerably modified, if (as I think possible) a different quality of powder should be substituted for that which is now in use for large guns. With a slower burning powder, the length would have to be increased, whilst the thickness at the immediate seat of the explosion might be diminished.

The shortness of a piece of this description would preclude its use for general purposes; but for siege operations by land or sea, it would prove very destructive. It might also be advantageously substituted, in many cases, for the ordinary mortar.

In attacking fortresses from the sea, floating bat-

teries armed with 68-pounder solid shot guns, and vessels carrying heavy rifled mortars, or howitzers, adapted for throwing iron shells, of nearly 2 cwt., at great elevations, would be of infinitely greater service than others armed only with rifled guns throwing iron shells of 100 lbs. weight. For, although a weighty shell is almost everything in vertical firing, yet a shell, even if it weighed 100 lbs., would not probably be so effective as a 68-lb. solid shot at 500 yards, or the ordinary battering distance; for the effect of impact being as the weight of the projectile and the square of the velocity (Naval Gunnery, page 77), the greater velocity (and solidity) of the 68 lb. shot will allow a superior effect to be obtained with it, at short distances.

I will now proceed to consider the comparative effects produced by rifled and smooth-bored guns when compound shot are used, and pieces of smaller calibre. Here, in applying the principle of the rifle, there are fewer difficulties to contend with, and the comparative advantages to be obtained by such an application, are considerably greater. As an example, take either a 12-Pr., a 24-Pr., or a 32-Pr. brass howitzer, as at present in use. The first of these, the 12-Pr. of 6½ cwt. —having an elevation of 5°*, and a charge of 1¼ lbs.

* I assume an elevation of 5°, because the difference in the ranges will be appreciable at that elevation, and it is also one which may be frequently used. But it must be remembered that the difference between the range of the long and round shell will continually increase with any increase in the elevation.

of powder—will throw a shell of 8 lbs. weight to a distance of 1100 yards. If this howitzer were rifled, the greatest general effect, perhaps, would be produced by the use of an expanding shell of about 9 lbs. weight, and three diameters long; this shell would have an advantage in weight, over the spherical shell of 8 lbs., as well as a much more extensive range. Were a shell of more than 9 lbs. weight employed, the charge of powder which could be conveniently used with so light a gun would be too small in proportion to the weight of the shell to produce a sufficient range at low elevations.

A rifled 12-Pr. howitzer,—with the bore reduced to a size that the shell, three diameters in length, shall weigh about 9 lbs.,—when fired with an elevation of 5°, and with a charge of 1¼ lbs. of powder, will throw the shell nearly 1700 yards; a distance one-half greater than that which, with the ordinary bore, it would propel a round shell of 8 lbs. weight. The advantages are here considerably more in favour of the rifled gun than in the preceding case. In the first place, the difference between the ranges of a round and a long shell is much greater when both are fired from a gun of this weight, than if they were fired from a gun of large size; also, the flight is comparatively more accurate, and the trajectory lower. A rifled gun, of 6½ cwt. only, could also be as quickly loaded as a smooth-bored gun of the same weight. As the object of rifled field pieces would be either to act in

unison with, or cope against the improved rifle muskets, their comparatively low trajectory and precision of fire might be considered, in certain cases, to counterbalance any disadvantage in other respects which might attend their use, such as their defective *ricochet*, &c. Besides an incomparable accuracy, a rifled gun of the above description would have the advantage in range and weight of projectile over either a 6-Pr. field piece, or a 12-Pr. howitzer, both of which would be of the same weight with it. It would also be equal to a 9-Pr. field piece, which is double the weight. The same kind of comparison may be instituted with respect to the other pieces which I have mentioned.*

I do not pretend to affirm that the use of rifled field pieces, to the entire exclusion of others, would be advantageous at present, although a time will arrive when a more extended experience with rifled guns will admit of their general use. There may also be many occasions on which round shells would be preferable to others, as for *ricochet* firing, for instance; but I

* A light description of field piece, which will give a shot of 1 lb. weight an effective range of 1000 yards, is reported to be in use in the Prussian service. If it were found advisable to adopt such a weapon, a wrought iron gun which would throw a shell of 3 lbs. weight with accuracy, to a much greater distance than 1000 yards, might be made sufficiently light for two or three men to work; and by simply fitting a percussion tube, or placing a percussion cap upon a nipple, at the fore end of it, (both of which could be done when loading,) the shell would be made to explode upon meeting the first obstacle, however slight.

am certainly of opinion that such field pieces as are used for throwing solid shot only, might be entirely abolished the service: For these, 12-Pr. and 24-Pr. howitzers, rifled on the principle which I have described, might be substituted with immense advantage, at all events, until time and experience have shown which is actually the best description of rifled gun for service. The alteration which I have suggested would be attended with the smallest possible expense, both with respect to its adoption, and suppression afterwards, when the best method shall have been determined by further experience; in which case they would simply have to be bored out afresh to fit them for service as ordinary howitzers. If *solid shot* guns, of the ordinary bore, were rifled, so great an effect could not be obtained with them, neither would they admit of being bored out anew, and would therefore be rendered unfit for any other purpose.

By the above method, a most efficient arm could easily, and at once, be introduced into the service, with the smallest possible expenditure, and without materially affecting existing arrangements; indeed, the service would be more uniform on this account.

Shells fired from guns of the above description would prove very advantageous substitutes for rockets; at all events, for those of a lighter sort. The men and horses now forming the rocket troops might, since the improvements in small arms, be more effectively employed in the Rifled Artillery Service. For incen-

diary purposes, at great distances, the shells might be fired at great elevations (*see* Frontispiece) in the manner of rockets, than which they would attain both greater range and greater accuracy.*

With naval armaments, the course which I have suggested for the land service could not generally be pursued with the same advantage. The armament of a large vessel is composed chiefly of guns of large calibre, and with these, as I have attempted to show, the advantages to be gained by the use of rifled projectiles are not so manifest as with those of smaller calibre. In addition to a heavy shot, naval guns require to be frequently fired with heavy charges; great point blank ranges—which cannot be had except with high velocities—being (as observed by Sir H. Douglas) a great desideratum. Great force of impact is also required, for attacking land batteries; and it is doubtful whether, from their small velocity, any long iron projectile (of a size which could be fired from a gun of equal weight) could be made to have a greater force of impact at five hundred yards than a 68 lb. solid round shot.

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* A 24-Pr. or 32-Pr. rifled howitzer constructed to throw shells, respectively of 18 and 24 lbs. weight, and of about three diameters long might be added with advantage to the armament of nearly all ships of war, one or two of each, according to the class of vessel. On board ship these shells would be much safer, both to carry and to use than rockets, and also more effective.

Recent experiments have incontestably shown that the use of all solid spherical shot below the weight of 32 lbs. may be entirely abolished; but it would take a very heavy elongated shot to compete in its effects with a 68 lb. solid shot, or to prove an efficient substitute for it.

In naval warfare great accuracy, extensive point blank range with low elevations, and a rapid service of the gun, appear to be the chief requisites. The power of merely throwing a heavy shell, unless combined with all the above-mentioned qualifications, could not give a vessel,—especially in single ship actions,—any great advantage, unless, indeed, she possessed in lieu of them a very great superiority in speed, so that she might choose her own distance for engaging the enemy.

To convert a 68-pounder solid shot gun into a rifled gun for the purpose of throwing elongated *iron* shells, of the same diameter, is simply to spoil a good gun, (especially for naval purposes,) in order to obtain a rifled gun of the least effective description. It has merely the advantage in range over a 68 lb. solid shot at elevations and distances, which would render the striking of an object at sea very problematical; whilst in close action, it would, for reasons which I have already enumerated, show a decided inferiority.

A gun-boat, armed with a 68-Pr. gun, and two 24-Pr. or 32-Pr. rifled howitzers, (to throw compound shells,) would have a much more formidable armament

than another carrying a rifled gun for throwing iron projectiles, and the two smooth-bored howitzers with which some of these vessels are furnished.

For vessels of light draught, and for such as usually carry a light broadside armament, a very efficient power might be obtained by employing rifled brass or wrought iron guns, weighing about 25 cwt. A 32-Pr. brass howitzer, lengthened, if necessary, about a foot and a half, would give nearly this weight.* A gun of this kind having a 4½ in. bore, and fired with a charge of about 4½ lbs. of powder, would throw shells of 32 lbs. weight, at elevations even below 5°, to a greater distance than would the heaviest 32-pounder iron gun in the service. The superiority, both in range and accuracy, of the former guns would be considerably augmented at elevations above 5°. A vessel could carry the same number of such guns as she could of 18-Pr. iron guns, and thus the strength of her armament would be nearly doubled. Rifled guns would also have double the range of *carronades* of equal weight—not to speak of their superior accuracy of fire.

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* With carriages on the non-recoil principle this weight might be considerably reduced, in fact, the ordinary brass howitzer of less than 20 cwt. might be used. The reader will be able to judge of the superior effect attainable with a rifled 32-Pr. brass howitzer, by a reference to the performances (at pages 89, 90, and 91) of a piece of this description which was kindly given to the author, for experimental purposes, by the late Secretary of War, Lord Panmure.

A 68-Pr. gun, rifled in a manner adapted for throwing a heavy compound shell, would have a great superiority, both as to range and accuracy, over one formed for throwing elongated *iron* projectiles. The effect which may be obtained with such a gun, however, is yet to be seen; inasmuch as cast iron is a very unsuitable metal for their construction, from its not possessing a sufficient degree of tension; and no other metal has yet been tried with good results.

If a gun of this description could be constructed, it would be infinitely better adapted for gun-boats than the Lancaster gun. And if considered objectionable for the broadside of a ship, it could be advantageously employed on the deck, where, from its superior range and accuracy of fire, it might be of essential service in crippling an enemy at the commencement of an action.*

Many persons, unacquainted with projectile effect, have supposed that because rifled cannon can be constructed to throw shells to distances of five miles and upwards, that it is possible for a ship at sea to destroy another at these great distances. I need only mention a few of the obstacles to this achievement to

* A rifled gun of wrought iron, on the model of a 68-Pr. 95 cwt. gun is about to be constructed for the Author; this gun which, with the permission of the Secretary of War, is to be tried at Shoeburyness, will have the bore of a 42-Pr., and will throw a compound shell of about one hundred and thirty to forty pounds weight.

show, even admitting it to be possible, that it is only one remove from impossibility. These great ranges are only attainable by elevating the guns to an angle of between 30° and 40°; so that if the shot were to strike a vessel at all, it would drop upon it at a very great angle; the distance also would have to be calculated within a few yards, at a glance. Those who know the immense practice required to judge the distance of an object only some hundreds of yards off, will be aware how the difficulty increases with the distance. If the object fired at is in motion, the time of the shot's flight must be calculated to a nicety, as well as the speed with which the object aimed at is moving, and the motion of the vessel from which the shot is fired. The state of the atmosphere has also to be considered, as well with respect to its effect upon the powder, and upon the friction of the shot passing out of the gun, as in estimating the distance. The direction of the wind, the angle of the shot's descent, the density of the different layers of the atmosphere through which the shot passes—for it ascends to a great height—even the rotundity of the earth's surface, must all be exactly estimated to ensure a long range shot striking an object—even as large as a first-rate ship—when fired at a very great elevation.

In fact, however perfect the construction of both gun and projectile, the flight of the latter is influenced by so many circumstances, totally distinct from the *mechanical* means employed in its projection, as almost

to preclude the possibility of any great advantage being acquired from the great range of rifled guns, except for the purpose of throwing shells into towns, or into masses of shipping, otherwise unapproachable.

The introduction into our naval service of rifled cannon throwing heavy shells with great precision will be attended with the important result that *speed* will become a matter of much greater moment than it is at present. The introduction of steam-power into our navy is a fact of more importance in naval combats at sea than that of long range guns, how powerful soever the latter may be. What would avail the superior armament of a vessel if the option of fighting remain with her opponent, which must always be the case when the latter can command a greater speed? The power too, of bringing an overwhelming force to bear upon a particular point in a given time, is of more importance than almost any other consideration.

The famous "*coup de boutoir*" of Napoleon, to which, (as related,) he frequently had recourse to gain, or to complete a victory, might be practised as effectively, with the aid of steam-power and heavy metal, in a general action at sea, as on land. Thus, if, at a critical moment a small reserve squadron, composed of powerful steam vessels of the highest speed, strongly manned, and armed with guns of the most destructive kind and (even if fewer in number,) of the heaviest calibre, could be directed at once against a given point of an enemy's line of battle, it might, in many instances,

convert what otherwise might be a doubtful conflict into a complete victory; and although it may, perhaps, be doubtful whether vessels of this description could be advantageously employed in a general action, except in the manner I have mentioned, still, a naval commander having such a force at his disposal could always (in the event of falling in with a hostile fleet) secure either the greatest results from a victory, or if too weak to come to an engagement, a powerful aid in affecting a retreat.

It is considered by many that the use of long range and powerful guns is hostile to the employment of large vessels. So far from this being the case they will probably be the cause of a larger class of vessels being constructed; for the simple reason, that great speed, combined with a powerful armament, can only be obtained in a high degree in large vessels. The distinction between vessels of different classes, however, will probably become much more marked, in proportion as a heavy armament, great speed, a light draught, or a combination of two of these qualities is required.

When visiting the fine American frigate, *Merrimac*, with a party of officers belonging to H.M.S. *Excellent*, I was particularly struck with what appeared to me a great defect, namely, her small steam power. If she could have steamed thirteen and a half, or fourteen, knots an hour, instead of about seven or eight, she would have been a match, with her powerful armament,

for almost any line-of-battle ship afloat. As it is, I question if she is nearly as efficient a ship-of-war as one of our own new frigates, of the *Shannon* or *Mersey* class.

With respect to the description of guns (Dahlgren's) with which the large American frigates are armed, ranging in calibre from nine to twelve inches, I am of opinion, that, for sea fighting, we have nothing to compete with them in our service. They may, perhaps, be open to the minor objection of being too light in the muzzle and chace, and more liable, thereby, to be fractured in action; but there is no doubt that the general *principle* of their construction is correct.*

Our own heavy guns are constructed upon a principle so false, that the only wonder is that so few accidents happen with them; those of the largest size are not only unsafe, but also very inferior in power to the American guns.

If, however, it should be discovered that rifled guns of six or eight tons weight—the weight of some of the guns employed in the American service—can be constructed of wrought iron, then, indeed, a powerful piece of ordnance will be obtained; a compound shell, of 2 cwt. and upwards, could be fired from it, and a greater range and accuracy combined, would probably be attainable, than could be acquired with any other description of gun, such as could with convenience be

* See last Chapter—On Gunpowder.

used. A fortress, or a floating battery, attacked with ordnance of this kind, could scarcely escape destruction.

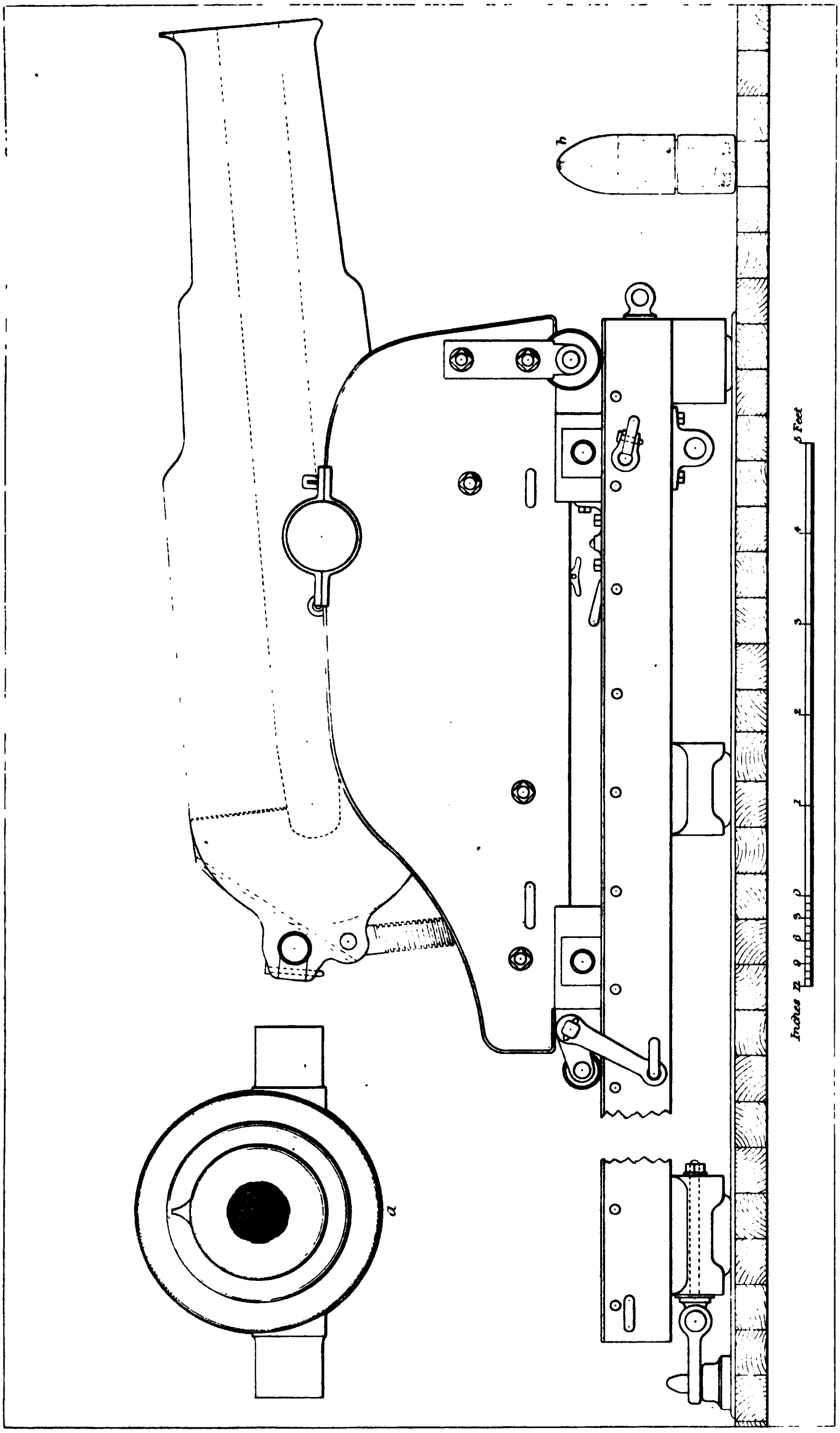
In Plate 7 is represented a gun of the above description. The length of the bore is nine feet, and the calibre eight inches; the metal which surrounds the charge is nearly twelve inches in thickness; this, (if the guns were constructed of the new puddled steel,) would probably be sufficient to give it ample strength and weight enough to prevent great recoil. A shell, of 2 cwt., of similar proportions to Fig. 4, Plate 3, and a charge of from 25 lbs. to 30 lbs. of powder, might be used with it; *a* is a front view of the same gun.

A long, low, strongly built vessel, possessing great steam power, armed with a gun of this kind, would prove infinitely more destructive than the steam battering-ram which has recently excited some attention. A vessel such as I have described would possess great advantages over a steam-ram, from the difficulty which would be experienced with the latter—first, in striking a vessel under sail, or steaming; and secondly, in getting disengaged from it afterwards.

Ten or twelve vessels of the above description—sea-going gun-boats—each armed with a heavy rifled gun to throw shells of 2 cwt.—and with steam-power sufficient to give them a speed of at least fourteen knots—would, at a distance of three miles,* lay any town on the coast in ashes, in a very short time, and with

* At this range, such a gun would not require an elevation of more than about 11°.

Plate 7.



perfect impunity. This may be accomplished, and *will* be; if not by our own nation, by another.

It is still questionable, however, whether the 11 or 12-inch guns, such as form the armament of the American corvette, *Niagara*, would not prove more destructive in close action—from their large diameter and heavy bursting charges—than even the powerful rifled guns which I have described. Before adopting rifled guns into our naval service, to the entire exclusion of smooth-bored guns of large calibre, much consideration would be necessary, and many experiments required to be made.

I see no reason, however, against the *acquisition* of such a gun as I have described. The only difficulties which lie in the way of it have already been once surmounted in the case of Messrs. Horsfall's 13-inch gun, and will, no doubt, be still more completely overcome. The great tensile strength which is required for guns constructed to throw compound shells, arises from the absence of windage, and also from the friction on the whole surface of the bore, which impedes the progress of the shell along the bore, and allows the fluid produced by the fired charge to accumulate behind the shell, and thus to exert a great strain on the gun.

Nearly the maximum results as to range and general effect—regarding the means employed—might be attained with the gun represented in Plate 7. Any larger piece of ordnance would not only be unmanageable, but probably unsafe; and although a larger gun

could, of course, throw a heavier projectile, still a *comparatively* greater effect would not be obtained with it, as the *range* of the larger shell would probably not be greater unless a higher velocity could be given to it; so that, to acquire the same *relative* effect, comparatively greater means would have to be employed.

The impact of heavy elongated compound shells is very slightly affected by the distance of the object aimed at; for the resistance which they suffer from the air is so small that their velocity of flight is very little diminished. I have remarked that when these projectiles are fired in a horizontal direction, their penetration into bodies generally takes place in an *upward* direction. This, I imagine, arises from the circumstance that their longer axis instead of coinciding throughout with their line of flight remains nearly parallel to itself, so that on striking the object the point of the shot has an upward direction; when the centre of gravity is in the fore part of the shot this effect is also frequently observable, but in a much less degree.

There can be no doubt that the advantages to be obtained with rifled ordnance are sufficient to warrant the conclusion that any improvement which tends to render them more efficient should command the most serious attention.

A considerable time will yet elapse before the best practical method for adapting their use to the different branches of our service will be obtained. To arrive at this result, the laws which govern the flight of elongated

projectiles, as well as the effect produced by different charges of powder, and many other points which have not yet been ascertained, must first be determined, otherwise no satisfactory result can possibly be obtained.

I cannot conclude this chapter without offering a few brief remarks respecting the Armstrong gun. As, however, I was allowed to see it and to be present at two of the trials, by the kind permission of Sir W. Armstrong, and as it appears to be considered unadvisable at present to give any minute details respecting it, it might not, perhaps, be considered quite proper were I to do so here. I will therefore confine myself to a brief notice of a few of the leading features of this beautiful piece of ordnance, such as are known to all the world.

The great merit of the Armstrong gun appears to consist in an admirable combination of certain approved principles rather than in the adaptation (except perhaps with regard to the manufacture of the gun) of any positively new invention. So happy a combination, however, could only result from numerous experiments conducted by a person possessing great mechanical skill, and a considerable knowledge of the science of gunnery.

The chief noticeable points in which this gun differs from those in ordinary use, are the metal of which it is constructed, and the (breech loading) principle upon which it acts.

With regard to the first of these points the success

of the Armstrong gun has placed beyond a doubt the fact that wrought iron and steel are admirably adapted for the construction of rifled field pieces and guns of a medium size. This, in itself, is an important fact. But as gun-metal is also well adapted for field pieces, the question whether it would be advisable to construct the smaller kind of guns of the above metals, will depend very much upon the time and expense which must necessarily be employed in their construction.

But should the construction of guns capable of throwing elongated shells, of a weight equal to that of the heaviest shot now in use, and upwards, be attended, as it probably will, with the same successful results, the employment of these metals—at least for *large rifled cannon*—will be imperative.

The *breech loading* principle has, I think, but few points to be remarked in its favour, compared with what may be urged against it. In this case, however, the combination by which the efficiency of the projectile is obtained is dependent entirely upon it. The great accuracy and range obtained with the Armstrong gun are startling from their novelty only, for as yet the rifled cannon is but in its infancy; and although the greatest possible praise is due to Sir W. Armstrong for the great ingenuity, as well as for the superior mechanical and scientific knowledge which he has displayed in the construction both of his gun and his projectiles, I am nevertheless fully persuaded that equally good

results will be obtained with a combination of a much more simple and inexpensive character.

The expenditure of time and labour which would be necessary to keep a large number of breech loading guns continually in a fit state for service, both when stored and in use, must prove a great obstacle to their general employment. Their general efficiency in action also has yet to be tested.

An additional obstacle presents itself in the fact that these guns would be very difficult to procure in a sufficient quantity on an emergency. The constant improvements which are likely to be made in breech loading pieces should also render us cautious about adopting any one method in particular until its superiority has been thoroughly established in actual service.

Breech loading guns, unless of the simplest construction, must always be objectionable in action. It may be an easy matter enough for well-trained men, under the immediate superintendence of a number of scientific officers at Shoeburyness, to fire so many rounds a minute; but would this be so in action? A system of breech loading, which a man of common capacity cannot learn and retain after ten minutes teaching; one which causes the employment of *detached pieces* of metal; any, in fact, which requires more than two simple movements, one to open and one to close the chamber, is open to objection. If it is considered necessary to employ breech loading pieces, they ought to be made to act with a movement which a man can

perform mechanically, as a soldier loads his musket, or a sportsman his gun, without having to think over it.

Great care must be taken, with guns upon this principle, that no escape of gas is allowed, otherwise the men between decks in a ship, or in a casemated battery, would be stifled in working them; not to speak of the loss of power occasioned by it.

Regarding the Armstrong gun as a scientific engine or machine for the projection of an elongated shot it is a *chef d'œuvre;* the accuracy obtained with it is remarkable. This is partly due to the delicacy of the the *sights* (which are so arranged as to allow for the lateral deflection), and to the absence of all recoil. If the maximum results attainable with rifled cannon depended entirely upon the combination employed in this case, we might safely assume that no other nation could produce a weapon to surpass it; it would, however, be presumptuous to assert this; in fact, both at home and abroad, results nearly approaching, if not equal to it, have been already obtained by much simpler means; and if a hostile nation could produce half a dozen guns to our one, it would be a matter for serious consideration, whether it would be to our advantage to employ guns constructed on this principle or not. As it is, other nations are already fully equipped with rifled cannon, whilst we possess some dozen experimental guns only. Even allowing that the rifled cannon of foreign nations are not equal to the two or three specimens of the Armstrong gun which we pos-

sess, we are by no means certain that they are not better adapted to the purposes of war.

So much has yet to be learned respecting rifled cannon, that no one can assert, at present, that the Armstrong gun—untried as it is—is really the best suited in every respect for actual warfare. Moreover, if we confine ourselves to guns constructed upon this principle, we can only have two hundred of them at the end of a year. But, supposing that, in six months' time, we are engaged in a great European war; and supposing, further, that the Armstrong gun be found, in actual service, to fail in achieving all that has been anticipated from it, what are we then to do for rifled cannon? Surely, some such method as that which I have suggested might be adopted, in order, by utilising the principle of the rifle, to place us at once on an equal footing with other nations; without prejudice to our finally adopting thatdescription of gun which is found by experience to be the most suitable for practical purposes—whether it be the Armstrong or any other. Perfect accuracy is, no doubt, highly desirable; but there are so many circumstances which must arise, in actual warfare, to preclude the possibility, (except under very peculiar circumstances,) of its attainment, that it is extremely questionable whether it is worth while sacrificing other important objects in attempting to acquire it. A difference of a few feet in the deflection, in a range of a couple of thousand yards so so, cannot surely be of so much importance as

to have a gun of simple construction and easily worked.

By following the course I have suggested, as heavy a projectile, as great a range, and very nearly if not quite as great a precision may be obtained as with the Armstrong gun; and the howitzers might be turned out by the dozen, and employed at a very little more than the ordinary expense; Sir W. Armstrong's fuzes might also be adapted with equally as good an effect to other projectiles, as to his own.

What we particularly require (for our coast defences) are large wrought iron rifled guns; with these we should possess an unequalled advantage, for it is questionable if elongated *compound* shells (the only kind with which a very superior effect is attainable) of upwards of 100lbs. weight, could be fired (with a proper charge) with perfect safety from cast iron guns; and out of England the difficulty of getting a large supply of wrought iron guns of large dimensions would be great. So that for floating batteries and coast defences we should be furnished with guns, which, properly distributed and managed, would put all idea of a successful attack upon our coasts quite out of the question. No rifled gun has yet been constructed of a size sufficiently large for those purposes, that is to say, large enough to compete with a 68 Pr. gun;* and it is questionable if a breech-loading

* I made the offer to the Minister of War to produce a gun of the size described at page 134, undertaking the whole risk in the

gun, capable of throwing shells of at least 1 cwt. with a proper velocity, without being too heavy and unmanageable, could be made; since the weight of the apparatus—even supposing that a proportionate thickness of metal only were required—will bear a much larger proportion to the whole weight of the gun in a large gun than in a small one.

No cost should be spared in a matter of this importance; besides, whatever may be the expense attending the production of a like description of ordnance, it would cost other nations at least as much, and probably more, to produce others of a similar kind. And every circumstance which tends to render war a more costly affair, gives England (from her wealth and mechanical skill) a considerable advantage, and serves also as an additional guarantee for the preservation of peace.

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event of failure, on condition, that if it accomplished certain results—much beyond anything yet attained — the expenses of the trial should be paid by the Government; but receiving an answer to the effect that I must produce the gun and projectiles *unconditionally*, I was compelled, as the expense would be at least eight or nine hundred pounds, to forego the trial.

ON THE RANGE OF ELONGATED PROJECTILES.

On no point do the results of practice differ so much from theory as in all that relates to the resistance of the air upon projectiles, and its effect upon their ranges. Experience has compelled many (myself amongst the number) occasionally to modify opinions too hastily formed in connection with this subject. The introduction of projectiles of an elongated form, and the very extensive ranges obtained with them when fired from the rifled musket, gave rise to many speculations as to what might be accomplished with cannon shot made on the same principle, and much disappointment has been expressed that the result has fallen short of what many predicted and more considered probable.

One writer, a thoroughly practical man in all that concerns small arms, stated it to be his opinion that with a shot of four inches in diameter, and three diameters in length, a range of ten miles was capable of being attained; whilst others have endeavoured to shew that even more than this could be achieved.

But if we examine the matter more closely, it will at once be evident that the greatest range which such shot could acquire under the most favourable circumstances—that is to say, with the present means of projecting them—is far below this. It was, and by many is still imagined, that by continually reducing the diameter of the shot, and increasing its length—thus reducing the resistance of the air to its flight—the range would be continually increased; but, independently of the difficulty of giving projectiles of more than a certain length a correct flight, there are other cogent reasons why this cannot be the case.

We will first suppose a shot fired in a vacuum, the forces of projection and gravitation being the only ones that act upon it; the range acquired by a shot fired under these circumstances is a matter very easily calculated; the method for computing it is given, among other writers, by Dr. Hutton. (*Theory and Practice of Gunnery, Tract* 37 ; see also "*Naval Gunnery,*" *by Sir H. Douglas,* pages 26 and 67.) It appears that if projected at an angle of 45°, and with a velocity of 2000 feet a second, a shot would have a range of nearly twenty-four miles. As the ranges of shot fired in a *vacuum* would vary as the squares of their velocities, a shot fired at the same angle with a velocity of 1000 feet a second would have a range of six miles only.

If we consider, then, the difficulty of giving a *mean* velocity of 1000 feet a second to a projectile of any

kind, during the time required for a flight of six miles, it will at once be evident that even this range is (with our present means,) extremely difficult of attainment. For a shot to acquire a range of six miles when fired in the air, that part of its surface opposed to the resistance of the air would have to be comparatively so small, that no shot could possibly acquire such a range, except one of extremely large dimensions projected with an initial velocity of more than 1,000 feet a second.

If, however, wrought iron or steel guns could be made of sufficient strength, (of which I think there can be doubt,) to throw long compound projectiles of a diameter of seven or eight inches with a proper velocity; the range of six miles, and even more, if it were desired, would be easily attainable. But in whatever proportion the weight of projectiles may be increased, or the resistance of the air (opposed to their flight) reduced, *a certain velocity of flight* must always be necessary for them to acquire a given range. The extended flight of heavy war rockets is entirely owing to their great mean velocity, acquired by opposing a continually greater force to the resistance of the air.*

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* Attempts have been made at various times to fire rockets from guns, but invariably without success, the rocket being usually blown into fragments. A little consideration of cause and effect will show the futility of such attempts; for even supposing that rockets could be fired from guns, no dependence could be placed upon their flight, as the impulse which they would receive from the gun would be

In fact, however exaggerated the dimensions of a shot, it could not be projected to a distance of six miles if the *mean* velocity of its flight were not higher than 1000 feet a second, unless, indeed—as I am induced to believe is frequently the case with long shot—the resistance opposed by the air to its *descent* tends to prolong its flight. For although by elongating a shot (of a given weight) the resistance to its *flight* is lessened; yet—on account of the greater longitudinal surface of the shot—the resistance opposed by the air to the action of gravity is increased. So that if a shot with a very small diametral surface, as compared with its length, were fired with a velocity not exceeding its *terminal velocity* (in which case the loss in velocity which it would sustain from the resistance of the air before it would be attracted to the earth would be scarcely appreciable) it might actually attain a greater range when fired in the air, paradoxical as it may appear, than if projected in a vacuum; since, owing to its undiminished velocity, and the resistance to its descent, the time of its flight would be more prolonged, and the curve consequently larger than it would be if

greater than that which they would receive from the firing of their composition. The latter would not therefore take effect until the velocity of the rocket was greatly reduced, in which case the direction of flight would be uncertain, for the impulse which the rocket would receive from the firing of the composition would always take effect in the direction of the longer axis of the rocket—a direction different from that which the rocket has in the gun.

the shot were fired (with an equal velocity) in a *vacuum*.*

In computing the ranges of shot projected in a *vacuum*, all that is necessary to consider is their velocity of projection, and the angle at which they are fired. When fired in the air, besides the resistance which is opposed to their flight, their *weight* also must be taken into account, since it enables them to overcome that resistance, and therefore, any increase in the size—and consequently in the terminal velocity of the shot—will be followed by an increase in their power of acquiring greater mean velocities, and therefore, greater ranges. Thus, for example, when heavy projectiles are fired with low velocities (below their terminal velocities) they acquire the ranges, or nearly so, which they would have if fired in a non-resisting medium, namely, as the square of the velocity; since they oppose to the resistance of the air a greater resistance, in their own weight. And when the velocities of projection are very low, the ranges vary in even a greater degree. For instance, a 13-inch mortar of 36 cwt., fired with a charge of 4½lbs. of powder, will throw a shell nearly 1,500 yards; and when the charge is increased to 9lbs., 2900 yards; but when the charge is diminished to 2lbs., the range is little more than 400 yards.† (See "*Artillerist's Manual*," *by*

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* See note, p. 91.

† The velocities acquired by shot are directly as the square roots of the charges of powder, and inversely as the square roots of the weight of the shot. ("*Artillerist's Manual*," page 190.)

Major Griffiths, R.A., Table of Mortar Practice, pp. 77, 78.)

The shot which can acquire the highest mean velocity in passing over a given space will have the lowest trajectory, *i.e.*, will require the least elevation to be given to the gun in firing at an object at a given distance. In proportion therefore as the elevation of the gun is low, and the time of flight small, the value of a high initial velocity increases.

Considering that the velocity given to elongated shot of all sizes, in horizontal firing, is very nearly the same; I think it will be found that the effect produced by any increase in the *length* of the projectile, used in this description of firing, will be less, in proportion as the diameter of the bore of the gun is increased; and my reasons for this belief are as follows:—If we duly consider the cause why so great an increase in the range attends an increase in the length of shot of a small diameter; we find that shot of small size suffer a comparative resistance from the air so much greater than those of a larger size, that any reduction in this resistance is immediately productive of a very great difference in their ranges. Thus an ordinary round musket bullet has an effective range as far as six or seven hundred yards; but by reducing its diameter, and increasing its length to three diameters—thereby considerably lessening the surface which it opposes to the air, without diminishing its weight—the range is more than doubled.

When, however, we have to deal with heavy cannon

shot, we find that the same comparative excess of range is impossible; for when fired in a horizontal direction, and with the comparatively small velocity with which alone rifled projectiles can be fired, the time which would elapse before the long shot could be drawn to the earth by the action of gravitation would be too small to admit of any advantage being acquired from that greater mean velocity of flight which it would have if fired at a great elevation.

Besides, large spherical shot have already surfaces so small in proportion to their weights, when compared with those of musket bullets; and consequently a mean velocity of flight (when fired at low elevations) so much more nearly approaching that which they would have in a *vacuum*, or, which would be due to their velocity; that to attempt to materially increase their range by lengthening the shot considerably, would be of little avail, unless an increased velocity of translation were given to them; and this, for various reasons already enumerated, is not always possible, even were it productive of a good result. In fact, I believe it will be found that when the diameter of a long projectile exceeds eight or nine inches, very little, if any difference will be perceptible in the range—except, perhaps, when they are fired at the highest elevations, —whether the shot be two or three diameters in length; supposing the initial velocities with which each is fired to be the same.

It will also probably be found, for the same reason,

that the ranges of long shot of different diameters, when they exceed a certain size, will not exhibit the same relative difference as those of round shot of different diameters. Indeed, in the case of long shot, the resistance of the air is so much reduced, that a shot of eight inches diameter, if fired with the ordinary velocity, would probably retain that velocity nearly undiminished throughout its flight; so that at whatever distance from it—within its range—an object were placed, it would always strike it with nearly the same force, irrespective of the distance; hence the destructive power which is to be obtained by the use of such projectiles when fired at great elevations.

For this reason too, when long compound shot of very large dimensions are used, as, for instance, of 8 in. diameter, it is very probable that the turn to be given to the rifling may be rather less than that determined by the rule I have previously explained. (See the previous chapter, "On the Influence of the Size of the Projectile on the Turn of the Rifling.") Unless such shot have very great velocities or very high elevations, the time of flight is not sufficient to allow of the diminished resistance of the air to increase the range.

If the velocity which can be conveniently given to long shot is found, by the ballistic pendulum, not to exceed 1000 feet a second, the angle of the turn, for shot of more than seven or eight inches in diameter, might remain the same; but if it be found that a higher velocity than the above can be given to them, the

angle must then be increased in the regular ratio; for the reason, that in the latter case the length of their flight will increase with their size, and therefore a proportionate rotary velocity must be given to them.

A proper consideration of the subject will always enable those who are interested in it to form a tolerably correct opinion respecting the manner in which all these circumstances influence the rotary velocity required for long projectiles, and to modify the turn in conformity with it. Experiments for ascertaining the velocities of long projectiles, with the ballistic pendulum, are very much required: until the result of such experiments is known, it will be impossible to calculate with any degree of exactness what range is attainable with projectiles of large diameter. If, (as I think probable,) the velocity acquired by elongated shot is found to be about 1200 feet a second, a compound shot of eight inches diameter and three diameters long, when fired at its highest effective elevation, may attain a range of nearly eight miles, or more, according to the initial velocity which they are found to acquire.

ON EXPERIMENTS IN GUNNERY.

GUNNERY furnishes no exception to the rule, that there must be a cause for every effect; indeed, in scarcely any investigation is a knowledge of causes more essential than in conducting experiments in gunnery. Hence, when we find that two shots, fired apparently under precisely the same circumstances, show a variation in their range, or in their accuracy, we know that a cause must exist why this should be the case; and, although the fact of the variation in the effect of shot fired under similar circumstances, shows that *general* rules only are applicable in gunnery, and that no single result is to be relied on, yet a proper study of cause and effect in this matter will considerably reduce the chances of failure.*

* These somewhat trite remarks were called forth by an observation which was made to the author by an Artillery officer of some eminence—to the effect that "the firing of the charge, with cannon, was attended with such varying results, that it was useless to think of applying any rule for regulating the thickness, or strength of metal, required for guns of different calibres!"

It is not sufficient, merely, to obtain a greater range, accuracy, or general effect; but we should know, also, how these results are obtained, if we wish to profit by them in the greatest possible degree.

Before any new principle can be successfully applied in practice, repeated failures must always be expected. I may go so far as to assert that they are absolutely *necessary* to the complete attainment of success. Because the Lancaster, Whitworth, and other guns may have failed in fulfilling the expectations that were formed respecting them, their trial is, by no means, on this account, to be considered as an entirely useless expenditure of either time or money. On the contrary, it was necessary that they should be made—and, no doubt, considerable advantage, in many respects, will arise from their having been made.

When men possessing mechanical skill in the highest degree—as Mr. Whitworth, for instance—undertake experiments with a view to any improvement in the construction of implements, whether of a warlike or a peaceful character, good must always result; for, even if they fail in establishing their views, considerable light will always be thrown upon the subject, to serve as a guide for the future. Still, although the aid of able mechanicians is of great importance in the practical application of the theory of rifled cannon and projectiles, the theory itself is, nevertheless, a philosophical rather than a mechanical question.

It will require systematic and well conducted ex-

periments, extending over a course of many years, before a sufficient knowledge can be acquired of all the circumstances attending the application of the principle of the rifle to cannon, to enable us to decide upon the best practical system for the construction, either of the gun or the projectile. The different methods of applying the principle of the rifle to cannon—as, by having the gun to load at the breech, or the muzzle; or, having a compound, or a homogeneous projectile—will each have to be the subject of numerous experiments.

It is all the more imperative that these experiments should be undertaken by the Government, inasmuch as no person—so small is the knowledge which has as yet been generally acquired of this subject—is at present really competent to give an opinion upon anything new in connection with it which may be brought before their notice. I think I should not be far wrong in asserting that only a very few persons connected with the War Department are yet fully aware either of the comprehensive nature of the subject of Rifled Cannon, or of their want of knowledge in everything relating to it. To stand by and witness the trial, at Woolwich or Shoeburyness, of a number of projectiles, or a new gun—the result, in general, of private experiment—teaches little or nothing. Much more is learned by firing a single shot,—made expressly for the purpose of ascertaining some particular effect—and by a thorough examination and careful study of all the circumstances attending its projection, than by merely

witnessing the firing of twenty thousand projectiles devised by other persons. The *results* obtained with the latter may be apparent enough, but the train of reasoning (the fruit of personal experience) which produces these results, remains altogether unknown; for although a man may communicate the result of his experiments, yet he cannot furnish another with his personal experience; and without this it is perfectly impossible to effect, or even to suggest, any important improvement.*

There is scarcely a question—if, indeed, there be one —in the whole subject of dynamics, or the laws which relate to a body in motion, which is not involved in the investigation of the circumstances attending the flight of elongated projectiles; these require to be thoroughly investigated and known, before any decided opinion can be given as to the best practical method for constructing rifled cannon. A system founded upon mere guesswork would have a very unsound basis.

It has been too much the custom to speak slightingly of *theory* in gunnery. This is probably owing to the unsatisfactory state of the ordinary theory of gunnery; but the acquisition, in this instance, of a sound theory,

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* The truth of this remark is exemplified in a striking manner by the fact that the rifled cannon and projectiles produced at Woolwich by Artillery officers, who had before them the results of all the experiments made from time to time at Shoeburyness, proved most signal failures. This fact also affords a proof of the defective nature of the ordinary theory of gunnery, and of its small utility in estimating the comparative results to be produced with long projectiles.

is of the highest importance. The stride which has been made in the practice of gunnery since Robins's experiments were made known, resulted from his discoveries respecting the laws which govern the flight of projectiles, and respecting the nature of the projecting force. When once a theory had been framed, based upon sound principles, the mechanical improvements followed as a matter of course.

Sufficient attention has not hitherto been paid to the correctness of the principles upon which the cannon and projectile should be constructed. To this, chiefly, must be attributed the failure of the Lancaster and Whitworth guns—the projectile in the former case, acting like a wedge; in the latter, like a lever, in the bore of the gun.

To produce any great and useful results, a combination of sound theoretical and practical knowledge is necessary, and this can only be obtained by a long and close study of the subject, and by numerous experiments carried on with unremitting attention.

No single invention—as of a projectile—a method of loading at the breech—a peculiar form of groove, or any other mechanical contrivance—is of the least use in itself, unless a perfect combination—such as the proper length of the gun—of the turn—the most suitable metal for the gun, &c.—is obtained for rendering it effective. If each of these be not adapted to the others, the whole must inevitable fail in practice. It is the difficulty of effecting this combination which

renders experiments with rifled guns so complicated and costly. If properly conducted experiments had been at first undertaken by the Government at their own expense, instead of relying upon the inventive and pecuniary resources of private individuals for the acquisition of their *data*,—which, to say the least, is a rather pitiful course to adopt; for, if a new thing is worth trying, it must surely be worth the cost of the trial—the public would have been spared the expense (amounting to between three and four hundred thousand pounds) of the Lancaster gun factory.

Notwithstanding, therefore, the numerous experiments which have been made in gunnery, and the immense mass of data which must have resulted from them; yet, owing to the desultory manner in which the experiments have been carried on, they have been productive of much fewer practical results, than we might reasonably have expected. Experiments with rifled cannon not only require to be conducted systematically; but, to be productive of real benefit, they also require to be conducted by properly qualified persons.

The questions which constantly arise in gunnery experiments are sometimes so complicated and difficult of solution, that none but a mathematician of the highest order can really ascertain the value of the results which are obtained. To conduct experiments in gunnery, therefore, in a proper manner, it is of the first importance to have a good mathematician to collect and arrange

the data, and to ascertain the exact numerical value of the results obtained.

It will be also necessary to have a practised experimentalist to profit by these results; one who, with a proper knowledge of cause and effect, is capable of suggesting the best method for the attainment of certain objects. A clever mechanician, to invent and judge of the means which can best be employed for carrying out the plans suggested, should also assist in conducting such experiments, to ensure their being attended with the most useful results.*

The whole of these qualifications are rarely combined in a single individual. Robins was a remarkable exception, and his experiments, in consequence, formed an era in gunnery.

But although the necessary qualities are seldom found in one person, there is no reason why several persons should not be selected, who would, collectively, possess them; and who might either be placed on the Rifled Ordnance Committee, or act with it in such a manner that their services would always be at its disposal, or at that of the presiding officer at Shoeburyness (an important office, for which no one could be better qualified than the gentleman who now fills it); the results of their operations to be finally submitted to

* The appointment (since this was written) of Sir W. Armstrong, as Engineer to the Rifled Ordnance Committee, will no doubt prove highly beneficial; in that he appears to possess the last named qualifications in a very eminent degree.

a committee of experienced military men of all services, who would be able to judge of their practical value.

A systematic course of experiments conducted under such joint superintendence would be the right course to take for acquiring the proper *data* respecting all the circumstances connected with rifled ordnance, in a much shorter time, and more satisfactorily, than could otherwise be the case. To conduct experiments in a desultory manner, is invariably a useless expenditure of both time and money.

It is impossible for a private individual to undertake such experiments on a sufficiently large scale to be productive of conclusive results; they should be conducted somewhat after the manner of Hutton's experiments, only on a much larger scale; each with a view to some well defined object. The following are amongst the chief circumstances in connection with rifled ordnance, respecting which some certain data are required, and each should therefore be the subject of a separate course of experiments.

1. Experiments with the ballistic pendulum for finding the different velocities of rifle shot under various circumstances; so that both the *initial* velocities given by different charges of powder, and the loss of velocity—occasioned by the resistance of the air—which the shot suffers in passing through different spaces, shall be thoroughly ascertained. At present literally nothing (certain) is known with respect to these points.

These experiments in the case of rifled shot ought to

be attended with better than ordinary results, as the pendulum could be placed at a greater distance than usual, on account of the superior accuracy of flight of rifled shot.

2. The different quantities of friction in the case of both compound and iron shot of different kinds; and the loss of range occasioned by it.

3. The effect produced upon the flight of long shot by any alteration in the position of the centre of gravity.

4. The effect produced by a difference in the forms of projectiles.*

5. The difference in the ranges and deflection produced by different elevations with shot of different lengths.

6. The circumstances attending the penetration of long projectiles into various substances.

7. The angular velocity required for shot of different sizes, forms, and density, when fired with different velocities and elevations.

8. The form of groove, (both for iron and compound projectiles,) which shall produce the necessary effect with the least amount of friction.

9. The strength of metal required in the gun, whether

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* It would be a great advantage if the establishment at Shoeburyness were furnished with the means—at least on a small scale—of casting, forging, or altering experimental projectiles, so that they might be tried without delay. It would be a great saving in time, and, eventually, in expense.

it be destined for the employment of iron, or of compound projectiles.

10. The *curves*, and also the *times* of flight, of long projectiles; in order to ascertain the best method for securing the greatest amount of efficiency, in firing them at high elevations.

11. The effect of windage, especially with iron projectiles.

12. The effect produced by altering the length of the *bore* of the gun.

Besides those which I have enumerated, there are many other points relative to which sufficient data must be fully acquired before unerring results can be obtained. Those who, like myself, have made many experiments on a smaller scale, have acquired sufficient data, perhaps, to form by comparison a general opinion upon all these questions, and (assisted by some acquaintance with the ordinary theory and practice of gunnery) may even have arrived at the power of estimating their effects with a certain degree of accuracy; but the *velocities* of rifled shot when fired with different charges, the *friction*, and many other points, can only be ascertained by a regular course of experiments with the ballistic and gun pendulums, and by other means of much too extensive a nature for a private person to undertake.

Whilst the necessary experiments are being carried on, there is no reason why the country should be deprived of the use of rifled cannon. The manufacture

of the Armstrong gun may be proceeded with; but we need not confine ourselves exclusively to guns of this particular description. There are several methods by which a supply of very efficient rifled cannon may be obtained without going to an exorbitant outlay in the exclusive adoption of cannon of the most expensive kind, previously to a thorough trial of their merits in actual service, or, before the utmost simplicity in their construction is attained. Enough has been said to show that the knowledge which has already been obtained, bears but a small proportion to that which remains to be acquired, and that further experiments are therefore necessary.

The accuracy attained with the Armstrong gun is a beautiful mechanical feat, but one which will be commonly performed (and by much simpler means,) when a better knowledge of the subject has been acquired; it has shown what can be effected with this particular combination, but little else has been learned from it; and until the truth concerning all the points which I have enumerated, and many others, be clearly ascertained, it will be impossible to decide as to which is positively the best system for the construction of rifled cannon.

To give an example of the change in opinion which experiment will effect; it is a remarkable fact that almost all the circumstances which the Ordnance Select Committee objected to, three or four years since, as perfectly inadmissible in the practical adaptation of the

principle of the rifle to cannon—such as a compound projectile—a projectile composed of many pieces—a breech-loading gun—a gun constructed of wrought iron, especially in such a manner as not to be homogeneous—are united in the Armstrong gun.

In like manner, it will probably happen, when further experiments are made, that the description of rifled gun which will be finally adopted, will differ as much from the experimental (for the whole are but experimental) guns which have been tried up to the present period, as these differ from the earlier attempts which were made; for, as yet, experiment has been directed almost solely to improvement in the mechanical application of a principle of which really very little (certain) is known; instead of being directed to the acquirement of a knowledge of what relates to the principle itself.

This it is which gives rise to such expensive blunders as the Lancaster gun factory; a greater blunder, however, will be committed if we adopt breech-loading guns to the exclusion of all others.* Fortunately, there is to be found amongst the members of each branch of our service a fund of sound common sense, which (and this, upon investigation, will be found, I believe, correct)

* The advantage of the breech-loading system, in allowing the men who serve the gun to be less exposed, is not so prominent with long-range guns as with others; since the former would more frequently be out of the range of musketry.

always leads, eventually, to the adoption of the best thing of its kind, when its superiority has been properly established; although, in most cases, it is effected by a very roundabout and expensive process.

By neglecting, therefore, in this instance, to make proper experiments, we throw away advantages which would enable us to acquire that superiority with regard to projectile effect, the possession of which (especially in a country like our own, the confines of which are all *coast*,) should be a matter of primary importance.

ON THE NATURE OF THE ACTION OF FIRED GUNPOWDER.

(*Read before the Royal Society, Dec. 16th,* 1858.)

A LONG interval has elapsed since the subject treated of in the following pages has engaged the attention of the Royal Society. I believe I am correct in stating that Count Rumford's paper on the initial force of gunpowder, read before this Society in 1797 (Philos. Trans., vol. 87), was the latest. Previously to this, the names of Leuwenhoek, Hauksbee, Robins, Hutton, and Ingenhausz appear in the Philosophical Transactions, in connection with the subject of the force of gunpowder. Each of these eminent persons contributed largely towards its development. In consequence, however, of their limited knowledge of the initial force and action of fired gunpowder, their theories remained very imperfect. Count Rumford, fully aware of these imperfections, instituted a course of experiments for the purpose of acquiring further data; but these experiments, although extremely valuable, failed in establishing any conclusive results.

The object of the present paper is to call attention to some remarkable circumstances attending the

ignition of gunpowder, and to point out their application to the construction of cannon, and, in general, to the theory of gunnery. In the course of it I shall endeavour to account for, and to reconcile, many well-known experimental facts, which are inconsistent with the hitherto received theory of the action of gunpowder; as well as to show the unsatisfactory nature of the existing theory in other respects. The present system of practical gunnery is encumbered with a mass of empirical formulæ which rather bewilder than assist the student, and afford no means of arriving at any satisfactory conclusions respecting either the relative length and strength required for different kinds of ordnance, or the initial velocities acquired by the projectile.

The theory which will be enunciated and explained in the present paper, is based upon numerous experiments of a most satisfactory and conclusive nature, some of which will be described; and although further experiments will, no doubt, be required, and time for its full development, still sufficient data have been obtained to establish its correctness, and to suggest a set of more accurate and simple formulæ, and thus to afford a satisfactory point of departure for future scientific enquiries.

The principal writers on the theory of gunnery are Robins and Hutton. Although many valuable experiments have been made, and empirical formulæ deduced,—among others, by Piobert and Mordecai,—the writings

of the two authors first named, contain all that has been done to reduce gunnery to a science. (The results of their investigations may be seen collected in Captain Boxer's Treatise on Artillery.) I will therefore proceed at once to explain the suppositions upon which their theory of the action of gunpowder depends.

They assume (Robins, Prop. 7, p. 74) that the whole of the powder is converted into an elastic fluid before the ball is sensibly moved from its place; and that the ball is then moved by the pressure of this elastic fluid gradually expanding. In this way the investigation of the velocity with which the ball leaves a piece of ordnance, presents no difficulty, and a formula is easily obtained for the velocity of a ball issuing from a cannon. This formula,* however, contains a quantity

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* Hutton's formula is $v^2 = \frac{\pi g m n a d^2}{w} \times \log\frac{b}{a}$; where

a = the length occupied by the charge;

b = the length of the bore;

d = the diameter of the ball, or of the bore;

$g = 16\frac{1}{12}$ or 16, the accelerating force of gravity;

$m = 230$, denoting the pressure of the atmosphere on the square inch, in ounces;

$n : 1$ the ratio of the first force of the fired gunpowder to the pressure of the atmosphere;

w = the weight of the ball.

Putting w' for the weight of the powder, Piobert's formula makes the velocity of the ball proportional to $\sqrt{\log\left(1+\frac{w'}{w}\right)}$; the

(n) the value of which is unknown, viz., the initial force of the elastic fluid generated from the gunpowder. Before the velocities given in different cases by this formula can be compared with the results of experiment, we must assign some value deduced from experiment to this quantity. In this way the formula is found to give the velocity with sufficient accuracy when the circumstances of discharge are not very different from those by means of which the numerical value of the initial force of the fired gunpowder is determined. But when a much larger charge of powder is employed, or a much longer or shorter gun, the formula gives results very erroneous.

The following conclusions result from the above suppositions.

(1) That whatever the quantity of powder which is used, the initial force of the elastic fluid must be the *same*, since the quantity of that fluid will always be proportional to that of the powder, and therefore to the space occupied by it—supposing that other circumstances are the same. When it has been found necessary, in order to explain observed facts, to sup-

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charge being such in proportion to the weight of the ball and to the length of the gun, that the powder may be supposed to act on the ball whilst the gaseous fluid retains a high degree of tension; *i.e.* the weight of the powder not being more than two-thirds that of the shot:—the length of the gun in calibres is however supposed constant, and the charge limited.

The practical formula is $v = 2000\sqrt{\frac{w'}{w}}$

pose the pressure of the fluid generated by the explosion of a large charge greater than that from a small one, it has been attributed to the greater heat, in the former case, increasing the tension of the fluid.*

(2) That when guns of different sizes are used, the weights of the shot and of the charge being proportional, the length of the gun should be increased in the same ratio as the size of the bore, in order to give the same velocity to the shot.† (*Hutton's Tracts*, vol. iii., p. 313.)

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* *(Hutton's Phil. Dictionary—Art. Gunpowder,* page 620.) "Hence it appears that any quantity of powder fired in any confined space, which it adequately fills, exerts at the instant of its explosion against the sides of the vessel containing it, and the bodies it impels before it, a force (according to Robins) equal to six tons and a half on the square inch—and it is proved by my Tracts, vol. iii., that the force is more than double this. This great force, however, diminishes as the fluid dilutes itself, and in that proportion, viz., in proportion to the space it occupies; it being only one-half the strength when it occupies a double space, one-third the strength when triple the space, and so on. Mr. Robins further supports the degree of heat to be a medium heat; but that, in the case of larger quantities of powder, the heat will be higher, and in very small quantities, lower: and that, therefore, in the former case the force will be somewhat more, and in the latter somewhat less than 1,000 times the force in pressure of the atmosphere."

† *(Treatise on Artillery, by Captain Boxer, R.A.,* page 72.) "It has already been stated that, in guns of different calibres, the length required in each to give their respective shot the same initial velocity, or nearly so, will not be the same number of *feet or inches*, but the same number of *calibres*; and why is this? Principally

But it is a well-known experimental fact, that length (in calibres) is not so important with large guns as with small. The barrel of a musket is about 67 calibres; that of a 9-pounder, 20 calibres; and of a 32-pounder, about 16 calibres;* and it is found that by increasing the length of a cannon beyond this extent the velocity is not increased to a degree at all proportionate.

Major Mordecai, of the United States Artillery, states that an addition of 9 calibres to a gun of 16 calibres in length, adds only $\frac{1}{17}$th to the velocity of a 12 lb. ball, when fired with a charge of 2 lbs.

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for the reason that the surfaces upon which the forces act in the two cases are in proportion to the *squares of the diameters*, whereas the masses which are propelled, or upon which these forces act, are in proportion to their *cubes;* and, therefore, with the same pressure upon every square inch, it requires the force to act through a greater distance in the one case than in the other to obtain the same velocity."

General Piobert—a high authority—however, clearly indicates (*Cours d'Artillerie*, page 81,) that *the knowledge of the theory of the movement of the projectile in the gun is yet to be acquired.*

* It is shown by Major Mordecai, in his valuable work, (*Experiments on Gunpowder*, pages 112, 13) that the velocity acquired by a 24-pr. shot, fired with a charge of powder one-fourth of its weight, from a gun with a bore 18½ calibres in length, is about 1600 feet a second; whilst the velocity acquired by a musket bullet, fired with a charge of rather more than one-fourth of its weight, is shown (at pp. 158, 161) to be about 1500 feet a second —the length of the bore in this case being upwards of 50 calibres.

and $\frac{1}{18}$th, when fired with a charge of 4 lbs. of powder. (*Naval Gunnery, by Sir H. Douglas*, p. 44, *Note.*)

It would also follow, from the theory of the eminent writers already named—

(3) That guns of different magnitudes, in which proportional charges of powder are used, should be of proportionate strength at the breech.

But this also is contrary to experience; for it is found that large guns are much more liable to burst than small ones, and require therefore to be much stronger in proportion at the breech.

The discrepancy of experiment with the theory is more manifest in these two cases when the charge of powder is considerably increased, and becomes so great that in some instances, as in large mortars, where heavy shells are fired at great elevations and with large charges of powder, the theory becomes quite useless.

In other cases, in order to make it agree with experiment, it is necessary to assume the initial force of the elastic fluid to be different for every charge of powder, and even for every length of gun, as may be seen from the tabular statements in Hutton's Tracts (vol. iii., p. 296). It is not difficult to see that the initial force may be greater when larger charges are used, as the heat of the fluid may be greater; but it is manifestly absurd to suppose that the length of the gun should have any influence on the initial force of

the powder. All these discrepancies conclusively prove that the recognised theory is incorrect; to these might be added, that it takes no notice of the effects of different kinds of powder, which are very observable in practice, and which will be alluded to at greater length presently.

It has been just remarked, that in order to make the theory agree with experiment, it is necessary to suppose the initial pressure of the fluid to be different for each charge of powder; it is also necessary to suppose that it varies with the weight of the shot. Indeed, it is laid down as a well-known fact by all writers on the subject, among whom we may instance Piobert, Gillion, Mordecai, and Sir Howard Douglas, that the tension or pressure of the elastic fluid increases with the resistance that is opposed to it.

It does not seem to have occurred to them that it is an absurdity to suppose the resistance opposed to the pressure of the fluid should increase that pressure, but it manifestly is so. At the same time the experimental facts from which this conclusion was drawn are undoubted, and must therefore admit of some other explanation.

Piobert gives as the result of his experiments that the first pressure of the fluid, when one bullet is placed in the barrel, is equal to 2500 atmospheres; when 2 bullets, 2700; when 3, 2880; and when 13 bullets are used, 3040 (F. Gillion, *Sur les Canons Rayés*, p. 49). The proper conclusion from the experiments

is, that the *total* pressure of the fluid during the passage of the bullets along the barrel is greater when their weight is increased; it being, as remarked above, manifestly absurd to suppose the *initial* pressure greater in one case than in another.

The explanation of the difference is to be looked for in a circumstance not taken any notice of in the theory, viz., the diminution of the heat, and consequently of the pressure, of the fluid, as it expands. In consequence of the heat of the expanded fluid being less, the pressure of the fluid will diminish much more rapidly as it expands, than is supposed by the theory; and every circumstance that tends to retard that expansion has the effect of maintaining the amount of the pressure at a higher magnitude.

Thus also is accounted for the very great value of the pressure found by Count Rumford, viz., 40,000 atmospheres. I propose to show presently that the value of this pressure has not been over-estimated by him.

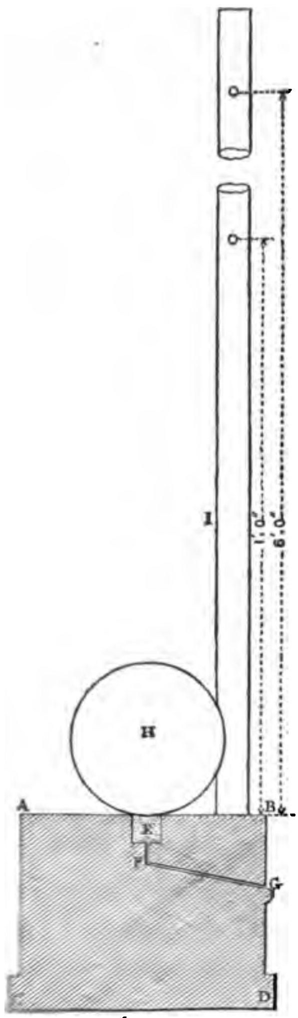
To explain this point more fully, it is very well known that when an elastic fluid is suddenly allowed to expand, so as to occupy a considerably larger space, its temperature at the same time falls, and therefore the pressure of the fluid is reduced more than it would have been, if, after occupying the larger space, its temperature had remained the same as originally. But the method by which Hutton and Robins have investigated the velocity of a ball moving in a cannon takes no account

of this change of pressure as consequent upon the change of temperature, and is therefore unable to explain philosophically the increased tension of the elastic fluid, when the resistance to its expansion is increased.

It has been already remarked, that the recognised theory supposes the ball to be projected from a cannon simply by the pressure of the elastic fluid; or that the conversion of the powder into the fluid has no special action on the ball. This theory was probably put forward by its distinguished authors, not as representing correctly the actual process that takes place in the firing of powder, but as an approximation to the truth; for when we consider the violent nature of the action that takes place in the conversion of the powder into an elastic fluid, it seems highly improbable that this act of conversion should have no effect in moving the shot. It was probably thought by Robins and Hutton that this effect, if there were any, might be taken into account by assigning a larger value to the initial pressure of the gas. This is true to a certain extent with guns of the ordinary lengths, but when we apply the formula to mortars, the results given by it differ very widely from the truth. Indeed, the high velocities given to heavy shells, when discharged from mortars, cannot be explained on the ordinary principles without assigning a very large value indeed to the initial force of the powder.

These considerations, in connection with the result of

a long series of experiments, carried on by myself, in different branches of artillery, caused me to suspect that there must be something in the initial action of powder different from that usually supposed—in fact that the ball begins to move in a cannon with a *finite* velocity, or that the initial action of the powder on the ball is *impulsive.* This being a conclusion opposed to the established views, I devised an experiment that should settle the question of *impulse** or *pressure* beyond all dispute. For this purpose I had an apparatus constructed of which the annexed diagram represents a section. A B C D is a mass of gun metal, in the upper part of which is a cavity E. From E proceeds a canal E F G, of small bore, terminating at G in a touch-hole. The cavity E, and the canal E F G, as above, being filled with powder, a cast-iron ball H, turned



* *Impulse* is not, perhaps, a strictly accurate term, but is used here for want of a better word. It is employed, in this case, to mark the

accurately spherical, is placed upon E, and the powder fired at G by a fuze.

In this apparatus a charge of powder of 1 dr. only was used, and a ball of 4 lbs. weight, and the ball was driven up to a height of about 5ft. 6in. With a chamber of twice the depth, and holding 2 drs., the ball was driven up to about double the height; and when a wooden ball of the same diameter was placed upon the chamber containing 1 dr., it was driven up to a height of about 30 feet; but the resistance of the air in the latter case must have been appreciable.

If the only force in the previous experiment had been the pressure of the elastic fluid, the ball would simply have been raised a sufficient height to admit of the escape of the fluid, and would have dropped back to its place without rising to any great height. This was the result anticipated by those friends interested in the

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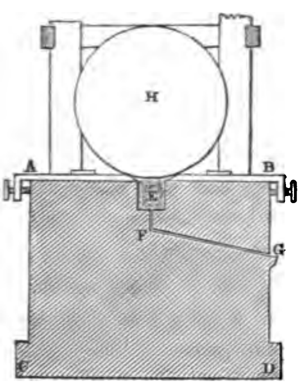
distinction between the real action of the powder and the supposed action of *pressure*. Pressure would imply that the elastic fluid exerts a *continuous* force, arising solely from the elasticity of the fluid, and varying in proportion to the spaces occupied by it; but by the word *impulse* I wish to convey the idea that the initial action of the powder is more like a sudden blow, and that its *continued* force is chiefly in consequence of the *gradual* conversion of the powder into an elastic fluid. The great force displayed by gunpowder arises, not so much from the elasticity of the fluid which is generated by its combustion, as from the actual *rapidity* of its combustion—its *explosive* force, in fact; which force, incredible as it may appear, has never been taken into consideration—in estimating the initial velocities of shot, &c.—in any work on gunnery extant.

subject of gunnery to whom I mentioned my views and my proposed experiment; and the very different result of the experiment shews the revolution that will be produced in the theory of gunnery, when these views are recognised.

The same experiment can be made under a form so simple as to admit of being performed by any person interested in the subject. If a pistol be taken, of which the barrel unscrews, and the barrel be taken off, and the chamber filled with powder, and the bullet placed thereon; then, on firing the pistol, the bullet ascends several feet, although there is no length of barrel through which the pressure of the elastic fluid could act.

In the experiment described above, when the ball was rested at a height of 1-8th of an inch from the powder (*see* woodcut), it was scarcely moved by the explosion of the powder. When the shot was placed close to the powder, but not touching it, it was driven upward about six inches. It was a noticeable circumstance, that the portion of the shot nearest the powder was covered, after the explosion, with a blood red substance, which rapidly assumed the usual black, or slate-coloured appearance, peculiar to the residue of fired gunpowder.



The inevitable conclusion from the experiment I have described, is, that at the instant of explosion, the force of the confined fluid is so great that it requires no appreciable time to impart a finite velocity to a heavy ball; which is the characteristic of *impulsive* forces.

If the space behind the ball, instead of a charge of powder, were occupied by a fluid of the elasticity, and heated to the temperature, of the gas of fired gunpowder, the results would be very different; for in this case no finite velocity would be acquired by the ball, at the first instant of its motion, and the initial pressure being the same in all cases, might then be compared to atmospheric pressure. It is, however, useless to attempt to compare a force so great, and so different in its nature from ordinary pressure, as that of fired gunpowder, with a finite pressure such as that of the atmosphere; and when experiments have been made specially with this view, the shorter the time during which the force of the gas has acted, and the more confined the powder, the greater has been the estimate of the force obtained; as is shewn in the case of Count Rumford's experiment.

It appears then that the action of a charge in a cannon maybe considered as of a compound character, consisting, firstly, of an impulse, which causes the ball to begin to move with a finite velocity; and secondly, of the pressure of the fluid generated from the powder; the latter of which only has hitherto been considered by writers on the subject of gunnery. The pressure will be continu-

ally augmented by the generation of fresh elastic fluid as the more perfect combustion of the powder takes place, until the whole is completely consumed; and when this is the case, the pressure of the fluid diminishes rapidly as it expands, and but little advantage is gained by giving greater length to the gun than is required to secure the complete combustion of the powder. Up to a certain quantity, (peculiar to the bore of the gun, and the quality of the powder used,) the whole of the charge may be *ignited* before the shot is sensibly moved; although *perfect combustion* (except of a comparatively small quantity) may not take place.

This theory will enable us to account for many facts indicated by practice and experiment, which have hitherto been very imperfectly explained. It is very well known that large charges of powder do not fire instantaneously; for a charge may be increased to such an extent that many of the grains will be driven out unfired. Also, that some kinds of powder ignite much more readily than others.

Now, supposing the action of powder to be such as I have just stated, it is clear that the initial impulse will be greater with a quick burning powder, than with a less explosive kind. Thus is explained the result indicated by the valuable experiments of Major Mordecai, that quick burning powder gave (*Experiments on Gunpowder*, p. 307,) a higher velocity to a ball when fired from a mortar; but slow burning powders were preferable when a cannon

was used. The old theory gave no explanation of this difference.

It also follows that every cause which retards the ignition of the powder, such for instance as mixing sawdust or lime with it, using gunpowder not granulated, or placing the powder in a chamber of suitable form, will diminish the initial impulse, and of course increase the subsequent effect of the powder. Hence, again, the more slowly the powder burns, the greater is the length of bore required to allow of its complete combustion. In illustration of this, we may notice that the Affghans and other tribes in India who manufacture their own powder, use small arms of very great length. All guns too in the infancy of artillery were much longer than at present, and much weaker at the breech, as may be seen in the case of the old guns at Dover, at Woolwich Arsenal, and St. James's Park.

Robins gives an account of some experiments made with the long gun still to be seen at Dover, by Eldred, who was master gunner at Dover in 1646, and wrote a book called the "Gunner's Glasse," which is one of the earliest English treatises on gunnery. This gun carries a 10 lb. shot, and its length is about 65 calibres. Eldred fired this gun several times with a charge of 18 lbs. of powder, and the range of the ball was 1200 yards, at an elevation of 2°, and 2000 when the elevation was $4\frac{3}{4}$°. This is a much larger charge than it would be safe to employ with the powder now in use in the English service, and the range obtained is also greater

than it would be possible to obtain with this gun by using a safe charge of the regulation powder.

This experiment agrees with the fact well known to those who are familiar with the practice of gunnery, that for some services the effect of powder is improved by mixing with it lime, or sawdust, so as to diminish the rapidity of its ignition; and also suggests that this practice might with advantage be more extensively pursued. On the other hand, in a few experiments where a charge of some of the fulminating powders, which ignite with extreme rapidity, has been used, the effect has been to burst the gun, while the ball is projected but a very short distance. This experiment was made by Count Rumford, and subsequently by General Piobert. Gun cotton has an effect, when used in guns, intermediate to those of fulminating powder and gunpowder.

These examples are sufficient to demonstrate the great importance of attending to the *quality* of the powder used, having regard to the service for which it is intended. As remarked already, the old theory of the action of gunpowder took no account of this difference in the action of different kinds of powder.

Having thus noticed the effects of using various kinds of powder, I proceed to the consideration of the change in the action of powder consequent on using larger guns, and proportionately larger charges of powder.

I have already stated that it has been long known

as the result of observation, that large guns require a much smaller comparative length than small ones, in order to give the same velocity to a ball; also that they require to be made much stronger in proportion at the breech. These facts are in direct opposition to the conclusions from the old theory, and have never, so far as I know, been satisfactorily explained upon sound theoretical principles.

These facts, together with the great tendency of large guns to burst, as well as the results of some experiments of my own, suggested to me that there must be a much greater increase of pressure when large charges of powder are used than had been hitherto supposed; more particularly at the instant of ignition.

It has been customary to attribute the increased effect of large charges of powder to the greater heat attending the explosion; but this seems an inadequate cause, even if the supposition of the greater heat be correct. In order to ascertain the initial effect of using a large charge of powder, I repeated the experiment described at pp. 176, 177, with apparatus of exactly double the size in all directions, so that the weights of the ball and of the powder were eight times those used in the former case. The result was that the larger shot of 6 inches diameter was driven to a height about *double* that to which the smaller rose, that is to say, to a height of about 11 feet.

These experiments have since been repeated in the

Royal Arsenal at Woolwich, in presence of the sub-committee appointed for the purpose.

From the nature of the experiment the whole effect is produced by the initial action of the powder, the subsequent expansion of the fluid having no effect on the ball (for *neither* shot was moved when placed one-eighth of an inch from the powder). The chamber which contained the larger charge exhibited a very different appearance, after the discharge, to that of the smaller; the former showing unmistakeable signs of the greater increase in the force of the powder. When the larger shot was placed upon the smaller chamber, it was projected to a height of about six inches, the chamber after the explosion showing no signs of a greater force having been exerted upon it than when the smaller shot was placed upon it; also, when the smaller shot was placed upon the larger chamber, it was propelled to a height of quite seventy or eighty feet, the state of the chamber after the explosion giving evidence that as great a force (or very nearly so) had been exerted upon it, as when the larger shot was fired from it. Hence it follows that the initial impulse of the powder on the ball is greater in proportion when a large charge is used than with a small one. My experiments seem to indicate that, within certain limits, the initial velocity imparted to the ball varies as $\frac{w^{\frac{4}{3}}}{w'}$, where w is the weight of the powder, and w' the weight of the ball.

Thus, when guns of different sizes are fired with relative charges of powder, the initial force exerted by the powder will actually increase in the ratio of the fourth power of the calibre; so that eight times the quantity of powder, when fired in a chamber of similar form, actually exerts an initial force *sixteen times as great* as that produced by the ignition of the smaller.

This greater impulse is easily accounted for, since the quantity of the powder, and consequently of the gas generated, is as the cube of the calibre, while the space to be traversed by the flame is only as the first power; and therefore, the quantity of powder ignited in the same proportionate time will be much greater in proportion. It is remarkable that this circumstance, which at once affords a simple explanation of the greater comparative force of the charge of powder in larger guns, and puts aside all the vague hypotheses which have hitherto obtained respecting the greater heat generated by the combustion of powder in larger quantities, *has never yet been noticed.* The fact that in my experiments the ball was placed in the chamber so as to be propelled in a vertical direction, does not affect the initial velocity of the ball. If any proof of this were required, it would be supplied by the statement of Capt. Boxer, in his treatise on Artillery (p. 79), that from experiments made at Metz, in 1840, with the ballistic pendulum, it appears that the inclination of the bore of the gun does not affect the initial velocity.

Since then, the powder, in large charges, ignites much more rapidly than in small, supposing that the charges of powder are of the same kind and placed in similar circumstances as regards the *form* of the chamber, it follows that the whole of the powder will be consumed in a shorter proportionate time, when the gun is large, than when it is smaller, and therefore a shorter proportionate length will be required in the bore, to give the same velocity to a ball.

Again, since the impulse on the ignition of the powder in a large gun is greater in proportion than in a smaller one, the large gun must be made of greater proportionate *strength* at the breech, in order to resist the force of the explosion.

Supposing that the impulse were simply proportional to the amount of the powder, it would suffice to make the thickness of the gun at the breech proportional to the calibre; but, as we have seen that the impulse increases in a higher ratio, the thickness of the gun must also increase in a higher ratio. This is well known to be the case in practice.

From this it is seen that the shorter comparative length, and the greater comparative strength at the breech, required for large guns than for smaller ones, are both consequences of the different action of the powder when used in larger quantities.

Some writers (Capt. Blakely amongst others) have attempted to shew, that the greater liability of large guns to burst, arises from their being subject to a severe

strain for a *longer time* than short ones.* It is argued that the large ball begins to move more slowly than the small one, and that consequently a strain is exerted for a longer time on the larger gun; but it is seen from

* In an article in the *Mechanics Magazine* of 26th September, 1857, "On Improvements in Ordnance," by Captain Blakely, R.A., are the following remarks:—"Large guns require more strength than small ones, as the powder occupying in each the same proportional space, the small shot moves in say $\frac{1}{300}$th of a second, a certain number of inches, the large shot in the same time moving fewer inches; so that at the end of that time, the gas in the small gun would have much more proportional room to expand in, and would therefore press less on the gun than in the larger one. Added to this, the large shot would require more time to get its velocity, and the pressure must remain on the gun so much longer."

The views embodied in the above extract agree perfectly with the ordinary theory, but are quite contrary to my experiments. According to those views, a greater pressure is first exerted upon guns of large size *after* the shot has commenced moving; whereas it has been shown by my experiments that a greater proportionate strain takes place at the first instant of the explosion. In the former case, the breech end, or seat of the explosion—and indeed all the relative parts—in large guns, would require to be of the same proportionate strength as those of a smaller calibre. In the latter case, it would have to be of a *greater* proportionate strength.

With regard to the theory that larger guns would require strengthening because the pressure (supposed in each case the same) of proportionate charges of powder acts for a *longer time* upon large guns than upon small, we have no evidence to shew that a metal so slightly elastic as cast-iron will resist a pressure which will cause it to break when the pressure is continued for a longer time.

Captain Blakely appears to have overlooked the fact that small

the result of my experiments, that the larger ball actually begins to move more rapidly than the small one, and therefore the large gun is subjected to the strain for a shorter, instead of a longer time; but so greatly does this strain increase with the size of the gun—from the actual increase in the initial pressure—that it is a matter for inquiry how it is that large guns are able to resist the force of the explosion at all, rather than why they burst.

Thus we see how readily the theory of the action of gunpowder here put forward, explains and reconciles experimental facts hitherto at variance with theory.*

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guns are submitted to a much severer test in the *proof* than large guns—the proof charge of a 9-pounder, for instance, being 9lbs. of powder, or three times the service charge—whilst that of a 68-pounder, 112 cwt. gun, is 30lbs., or one half more only than the service charge. Supposing therefore that Captain Blakeley's (or the ordinary) theory of pressure were correct, large guns would never, under any circumstances, be subject to the strain which small guns suffer in the proof.

* An attempt was made, (by Capt. Boxer, R.A.,) to account for the greater height to which the larger shot was driven in my experiments, by the supposition that the fluid of the exploded powder continued to act upon the shot after it was in motion. If this were the case it must have done so for a very short distance, for (as I have explained) when either shot was placed $\frac{1}{8}$ of an inch only from the chamber, the charge failed to move it. But allowing that the fluid acted in this manner, it must have exerted the same influence on both shot, and explains in no way why the larger shot was driven to double the height of the smaller: on the contrary, if anything, it would influence the smaller (supposing the initial force

The theory now advanced, that the initial action of powder upon a projectile is *impulsive* instead of being

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of the powder the same in both instances) in a higher degree than the larger; its surface, as compared with its weight, being greater.

Putting aside the futility of an argument which would tend to show that a heavy body in motion could receive a considerable accession of velocity from the *pressure* of a fluid which is allowed freely to expand in the open air; the fact that the larger shot, when placed uearly *on* the powder, that is to say, in a position $\frac{1}{32}$ part of an inch only further from the charge than when it rested on the chamber, received a velocity which drove it up one foot only, proves, by the second law of motion, that the ball must have received its whole impulse (minus that which would drive it up one foot) in the space of $\frac{1}{32}$ of an inch, which is sufficient evidence that the force is an impulsive one.

Capt. Boxer asserted that there was no proof that large guns were required to be of less length (in calibres) than small ones. He admitted, however, the correctness of my theory, that the same comparative charges when fired in guns of various calibres, must be converted into fluid much more rapidly in large guns than in small: whether therefore the initial action of the powder be that of an impulse or a pressure, he must necessarily admit that it must be *stronger*. It follows, therefore, as the shot must receive a given velocity, in either case, in a comparatively shorter space with large guns than with small, that the former will require to be of a fewer number of calibres in length than the latter. (See note, page 117.)

It would scarcely, perhaps, be fair to assume that Captain Boxer stated altogether his real opinions on this occasion; since he appeared to be actuated (unfortunately for the weight and consistency of his arguments,) by motives of rather a conflicting nature; the principal one being to establish a claim (in virtue of his unsupported remark, referred to at page 191) to whatever merit there might be in the introduction or formation of the theory here put forward; or, failing in this, to prove that the whole was a delusion!

that of ordinary pressure, has scarcely even been hinted at by any writers on the subject of gunnery. They have all, with one or two exceptions, supposed that the whole action of powder is that which is due alone to the expansive power of the generated gas; although admitting that there is a good deal of obscurity about the action of powder on this supposition, as well as that there are some facts extremely difficult to explain.

General Piobert in his treatise (*Cours d' Artillerie*, p. 48) relates an experiment made in 1826, by General Pelletier. Several pounds (4) of powder were spread on a light wooden table, which was placed upon soft earth; the powder being inflamed caused only a slight depression of the table; but when the experiment was varied by placing a sheet of paper over the powder, the table was shattered to atoms. Piobert concludes from this experiment that the action of the powder is a pressure which increases with any resistance opposed to it; but the experiment, on the contrary, proves that the initial action is *impulsive*, since it would have required but a very moderate *pressure* to remove the paper—a pressure, in fact, that would have exercised no injurious effects on the table.

I mentioned that there were one or two writers who had ventured to offer different opinions from those usually entertained respecting the initial action of powder. One of those writers, Count Rumford, assigns a very large value to the initial force of fired gunpowder, and a very small value to the elasticity of the

fluid. He supposes that this great initial force consists in the temporary action of a fluid not permanently elastic. At page 232, vol. 87, *Phil. Trans.*, he has these remarks:—"There is no doubt that the permanently elastic fluids generated in the combustion of gunpowder *assist* in producing those effects which result from its explosion; but it will be found, I believe, upon ascertaining the real expansive force of fired gunpowder, that this cause alone is quite inadequate to the effects actually produced; and that therefore the agency of some other power must necessarily be called to its assistance." Count Rumford however made no attempt to apply this practically.

The second of these writers, Capt. Boxer, in his "Lectures on the Science of Gunnery," printed in 1854, remarking upon Count Rumford's experiment for ascertaining the force of fired gunpowder, observes "that the effect there produced is not merely that of an ordinary pressure steadily applied, but rather the effect which would result from a body in motion coming in contact with a body at rest, or, in other words, be similar to a blow."

In Capt. Boxer's treatise of artillery, which was published two years later, he, too, fails to apply this in any way to the theory of gunnery, or the construction of cannon, for he supposes, with other writers, that the initial force of the powder upon the shot is the same in all cases: and in all the formulæ there collected, given for ascertaining the velocities of shot,

the action of the fired gunpowder upon the shot is assumed to be that of *pressure*, or that which is due to the elasticity of the fluid alone; an assumption which is totally at variance with his previous remark on Count Rumford's experiment; unless, by some extraordinary train of reasoning, he supposes that the powder acts with an impulsive force on the sides of a chamber in which it is completely confined, but not upon a shot placed before the powder in the chamber of a gun.

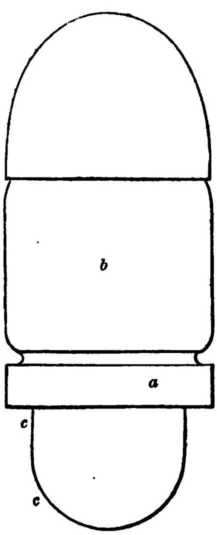
All the experiments hitherto made with cannon have failed to shew the initial action of the powder, because they gave the result of the *total* action without distinguishing the initial from the subsequent action.

The experiments of Capt. Dahlgren, of the United States Navy, shewed that a greater strength was required at the breech with large guns than was previously supposed, and that the requisite strength diminished rapidly from the breech to the muzzle.

These experiments, of which no detailed account has been published, were made by boring a series of holes in a 68-pounder gun, perpendicular to its length. All of these holes being plugged, with the exception of one, a bullet was placed in this, and the cannon fired in the ordinary way. The velocity with which the bullet issued being determined by the ballistic pendulum, indicated the pressure of the gas in the bore of the cannon at that point of its length, and consequently, the thickness of the gun necessary to resist that pressure. These experiments showed a much greater

pressure at the breech than had been previously supposed, and the Americans have constructed guns of the figure thus indicated. This perfectly agrees with the theory of the action of powder here laid down, but it would not have been possible to deduce the theory from these experiments alone.

As I have said that none of the ordinary experiments with cannon point out the value of the initial action of the powder, it may probably be interesting to describe the experiment which first called my attention more particularly to this point.



The accompanying woodcut represents a shell constructed after my own design, for experimental purposes.* In the figure, *a*, is an iron ring, which was driven up by the first impulse of the powder before the shell was sensibly moved from its place, and expanded the leaden band, *b*, so as to prevent windage.

A great number of shells, constructed on this model, of 1 lb. weight (the diameter being 1.25 in.,) were fired with superior effect both as to accuracy and range. When, however, I had shells of a large size constructed on the same model,

* This shell is on the same principle as that described at p. 86, and a figure representing a section of it is given on Plate 3, Fig 5.

weighing 32 lb., the result of firing them was, that the shell was driven out without the lead expanding, and, in a few instances, with the hinder part (*c*) broken. Now, when the smaller shell was fired, the elastic fluid traversed the space (*c c*) to the ring, and expanded it, before the shell was sensibly moved. This was proved by firing one of the shells from a gun which had been cut down to a length only sufficient to admit of the shell being placed in it. But when the larger shells were fired, the force of the powder actually moved the shell before the expanding fluid had time to traverse the distance to the iron ring.

In order to obtain a successful result with the larger shells, I was obliged to increase greatly the breadth of the ring, and to diminish the diameter of the shell at (*c c*), as well as to adopt several contrivances for causing the leaden band to expand as quickly as possible.

By this means I ultimately fired the larger shells with very good effect. But the failure in the first instance being so contrary to what would have been anticipated from the recognised theory, convinced me that the initial action must be very different from the pressure of an elastic fluid, as always supposed hitherto.

To recapitulate the conclusions to which my experiments point, and which have never been put forward previously:—

First. The initial action, when a charge of powder is

fired in a gun, is an impulse* which causes the ball to commence moving at once with a finite velocity.

Secondly. When the charge of powder is increased, this impulse increases more rapidly, or in a higher ratio, than the quantity of powder; and, consequently, the subsequent action of the powder is diminished.

This circumstance, which, strange to say, has escaped the observation of even the most eminent writers and experimentalists, is due to the fact of the gradual conversion of the powder into an elastic fluid.†

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* Subsequent investigation showed me (as I have remarked) that Count Rumford and Captain Boxer had hazarded similar conjectures, although neither appears to have been aware of the important consequences which would follow any proof of the incorrectness of the ordinary theory of pressure, and therefore made no attempt at any practical application of their ideas.

† The question whether the whole of a charge of powder is fired before the shot is moved, was determined in the year 1742 by a Committee of the Royal Society, formed, at the suggestion of Dr. Jurin, for the purpose of making some experiments in connection with this subject. The results, which proved that the whole of the charge was *not* fired, may be seen in vol. 42, page 172, of the *Philosophical Transactions*.

That these results were not turned to practical account probably arose from the defective state of the theory of the action of powder—and it was, no doubt, imagined that the effect produced by the gradual ignition of the powder was *proportional* in guns of all calibres.

This cannot, however, be the case either with different quantities, or with different qualities of powder; for if two charges of equal size be fired, one of a quick, and the other of a more slowly

Thus the ranges of the balls will not increase so rapidly as those of the shells.

Perhaps the most important practical error, which will be exploded by a recognition of this theory, is that which has hitherto existed with regard to the initial effect of the charge of powder upon the *gun*. We now see that this becomes relatively greater in a ratio, which can be determined by experiment; and also, as the gun is increased in calibre, that the shot is moved with a continually greater initial velocity; and therefore the strain upon all other parts of the gun, except the breech, where it continually increases, becomes less. This, it is needless to add, is a most important fact to establish.

Hence, a 68-pr. gun, fired with the service charge of powder, *i.e.*, a third of the weight of the shot, will have nearly the same strain upon the breech end (supposing the powder to be all of the same quality), that a 9-pr. gun (which has a bore of half the diameter,) would experience were the proof charge continually used; so that, in fact, a 9-pr., of similar proportions to a 68-pr. gun, has, relatively, at least double the strength at the breech end; or twice the power of resisting the first strain, caused by the discharge before the shot is moved. We need scarcely wonder then at the liability of large guns to burst. It shows how fallacious have been the opinions respecting the relative strength of cast-iron guns.

The accompanying figures will serve to illustrate

the proportionate increase in the strength and length*
required for guns of various calibres.

Some idea may be formed of the force exerted upon the gun by the powder, before the shot

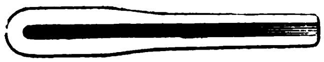

Fig. 1. *Diameter of Bore*, 3 *inches*.
Length of Bore, 25 *Calibres*.

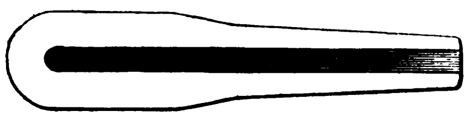

Fig. 2. *Diameter of Bore*, 6 *inches*.
Length of Bore 17.75 *Calibres*.

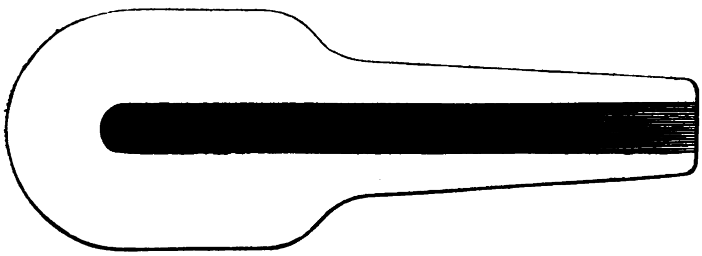

Fig. 3. *Diameter of Bore*, 12 *inches*. *Length of bore*, 12·75 *Calibres*.

is moved, as compared with that which is subsequently exerted upon it, from an experiment which I

* Since we find that the *initial* velocity which shot of different diameters receive, when fired with proportionate charges, is in the ratio of the square root of the calibre, we may reasonably infer that the length (in calibres) of guns of different calibres should vary nearly in the same ratio. For example: at page 171 (note) I have given an extract from Major Mordecai's "*Experiments*," showing the different velocities acquired by a 24 lb. shot, and a musket bullet, when

made for the purpose of ascertaining the proportion which the initial force of the charge of powder, bore to its *whole* force. I caused a tube, three inches long, (the diameter of the smaller ball in the former experiment,) to be screwed tightly on to the block of gun-metal in which the chamber, containing one dram of powder, was formed. The cubic content of this tube was 280 times greater than that of the chamber. Upon firing the charge of one dram, the ball was driven to the height of about 30 feet, or about six times the height to which it was driven without the tube. Upon employing a tube of rather more than two feet in length (the cubic content of which was 2,000 times greater than that of the chamber containing the powder), the difference caused by the use of a longer tube was scarcely perceptible. The initial force, therefore, in this instance, appeared to be to the whole force nearly in the ratio of 1 to $\sqrt{6}$; the resistance of the air, in either case, being scarcely appreciable.

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fired with proportionate charges of powder. Here the diameter of the 24 pounder gun was 5.82 in., that of the musket 0.69 in.; the former being rather more than eight times the diameter of the latter. If, therefore, we multiply the length (in calibres) of the 24-pounder gun (18-5) by 2.82 (the square root of 8) it will give more than 50 calibres—the length required for the musket, in order to give the bullet the same initial velocity as the 24 lb. shot. In the instance given, at page 171, it will be seen how very nearly this approaches to the truth—the large shot acquring, indeed, rather a higher velocity than the bullet.

In these instances the whole force of the powder, excepting that which escaped by the windage, acted upon the shot;—the size of the tube being in such proportion to the size of the chamber as to allow of this. When we consider that the tube, or bore, of a cannon is rarely more than eight or ten times the size of the part occupied by the powder, it may be imagined how large a proportion the initial force of the charge of powder, in a gun, must bear to the whole force.

Several facts which have remained altogether unknown, or respecting which vague hypotheses only have been formed; such as the first movement of a shot when the charge of powder is ignited; the initial effect of various charges in the same gun—both upon the gun and upon the shot—with many other circumstances of greater or less importance, may now be clearly ascertained, and the knowledge thus acquired applied to the construction of guns, so that they may be made in future in a manner, which, while economising the metal, will preclude the possibility of their bursting from any other cause than defects in the metal itself.

Another important practical fact may also be deduced from this new theory, namely, that when the form or make of guns of different calibres is constant, the *quality of the powder*—to give the shot equal velocities—must vary according to the calibre of the guns; and, when the quality of the powder is constant, the *form and proportions of guns* must vary with the calibre.

It would be out of place here to attempt a mathematical

investigation of the full effects of this action of gunpowder now for the first time pointed out. I may notice, however, that in place of the formulæ given by Hutton and Robins for the velocity of a ball issuing from a cannon viz., $v^2 = \frac{\pi g m n a d^2}{w} \times log \frac{b}{a}$,— where b is the length of the bore, and a the length occupied by the charge of powder, we shall have the following, $v^2 = V^2 + \frac{\pi g m n' a d^2}{w} \times log \frac{b}{a}$,— where V is the velocity with which the ball begins to move, and is to be determined by experiment for each particular kind of powder, and for each charge. A sufficient number of experiments would enable us to assign an empirical formula for V, which will probably vary inversely as w (the weight of the shot), as in the formula I have already suggested.

All the experiments which I have as yet made indicate that V does not increase in proportion to the weight of the powder used, but in a higher proportion. The quantity n' in the formula must depend for its value partly on that of V, being smaller as V is larger, so that v will be a function of the weight of the powder used, or rather of the fraction $\frac{w'}{w}$ w' being the weight of the powder, and w of the shot.

Before concluding this subject, there is a circumstance attending the firing of several balls from the same gun to which I would particularly call attention, as it bears both upon the question of the complete ignition of the charge before the shot is moved from

its place, and upon the nature of the action of gunpowder generally.

When Robins wished to prove beyond a doubt his principle, that the whole of the charge was converted into an elastic fluid, before the shot was sensibly moved from its place, he made the experiment of placing two or three bullets in the same gun instead of one, firing them with the same charge of powder with which he had already fired the single ball.

He observes (*New Principles of Gunnery*, page 80): "I considered that if a part only of the powder is fired, and that successively, then, by laying a greater weight before the charge (suppose two or three bullets instead of one), a greater quantity of powder would be necessarily fired, since a heavier weight would be a longer time in passing through the barrel. Whence it should follow that two or three bullets would be impelled by a much greater force than one only. But the contrary to this appears by experiment; by firing one, two, or three bullets, laid contiguous to each other, with the same charge respectively, I have found that their velocities are not much different from the reciprocal of the sub-duplicate of their quantities of matter. * * * From hence it appears, that, whether the piece be loaded with a greater or less weight of bullet, the action of the powder is nearly the same; since all mathematicians know, that if bodies containing different quantities of matter are successively impelled through the same space by the same power, acting with a deter-

mined force at each point of that space, then the velocities given to those different bodies will be reciprocally in the sub-duplicate ratio of their quantities of matter. * * * If the common opinion was true, that a small part only of the powder fires at first, and other parts of it successively, as the bullet passes through the barrel, and that a considerable part of it is often blown out of the piece without firing at all, then the velocity, which three bullets received from the explosion, ought to have been much greater than we have ever found it to be; since the time of the passage of three bullets through the barrel being nearly double the time in which one passes, it should happen, according to this vulgar supposition, that in a double time a much greater quantity of the powder should be fired, and, consequently, a greater force should have been produeed than what acted on the single bullet only, contrary to all experiments."*

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* Robins further observes, that although, in general, the velocities were reciprocally in the sub-duplicate ratio of the number of bullets, yet they were sometimes greater; but never more (when three bullets were fired) than one-eighth of the whole. If the reader will turn to the last paragraph at page 173, he will see how closely this agrees with Piobert's experiments. Robins, however, differs from Piobert in his manner of accounting for the excess of velocity; instead of ascribing it (as Piobert does) to the increased tension of the elastic fluid, he supposes that the flame, escaping (by the windage) past the first bullet, acts upon those beyond it.

A series of ballistic pendulum experiments, with elongated pro-

Now if the existing theory of the action of gunpowder (that it acts by *pressure*) is correct, Robins is right in his conclusion, and the whole of the charge must undergo perfect combustion before the shot is moved; but if, as we know to be the case by experiment, the whole of the charge is *not* consumed before the shot is moved, Robins's conclusions, as well as the present theory of pressure, must be erroneous. If, however, we accept the fact that the first action of fired powder is *impulsive*, we have a solution of the whole question, as in that case the whole of the powder need not necessarily be consumed before the shot is moved. The relative velocities acquired by the balls may also be easily accounted for, since it is clear that the *whole* force of a charge of powder, (in a gun of a length sufficient to ensure the perfect combustion of the charge,) can neither be increased nor diminished by altering the weight of the object to be moved; although the manner of its action will vary with the form of the chamber, or the manner in which the charge is placed therein.

In another experiment of Robins's (*New Principles of Gunnery*, p. 116), he placed the bullet eleven inches from the breech of the gun, and instead of confining the charge in the usual manner, he scattered it behind

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jectiles, would throw considerable light on this question; and I believe it will be found that the explanation which I have given at page 174, is the correct one.

the ball in as uniform a manner as he could. The result was, that the velocity of the ball was considerably diminished; an effect which he ascribed to the "intestine motion of the flame;" and he remarks that "the accension of the powder thus distributed through a so much larger space than what it could fill, must have produced many reverberations and pulsations of the flame, and from these internal agitations of the fluid, its pressure on the containing surface will (as in the case of all other fluids) be considerably diminished."

A better explanation of this diminution of force will, however, be found, if we consider that the initial action of the powder is *impulsive*;* as in

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* The impulsive nature of the action of gunpowder is probably the chief cause of the bursting of the Whitworth and Lancaster guns. These guns may be said to burst usually from accidental causes, rather than from the actual strain which is due to a given charge of powder. The projectile, of an irregular form, lying in the bore—which it does not fill—is suddenly moved from a state of rest, with more or less velocity, in a forward direction, where (from the *play* which the projectile has in the bore) it encounters a sudden resistance; this gives it an instant check, which is more or less injurious according to the position of the projectile when it meets the opposing surface of the bore; so that it frequently happens, either that the projectile (if of cast-iron) breaks, or (if of wrought iron) gets jammed; thus its progress through the bore is retarded, and, the gas not being allowed a sufficiently rapid escape, the gun bursts. A very slight impediment will suffice for this—as testified by the well-known fact of the bursting of fowling pieces when a small quantity of earth or snow is allowed to get jammed

this case the explosive action of the powder would be very much diminished in force by being scattered (as in Robins's experiment), owing to the slowness of its ignition.

The force of a charge of powder was found (by Count Rumford, *Phil. Tran.*, vol. 71, p. 277) to be weakest when the *vent* was placed at the top of the charge, *i.e.* near the ball—especially with large charges. This was probably owing to the fact that the first impulse of the powder upon the shot was weaker, on account of the smaller portion, which (in this case) was lighted before its action on the shot took place. At page 273 of the same volume, Count Rumford remarks that nothing can with certainty be determined with respect to the best form of chamber for pieces of ordnance, or the best situation of the vent, nor can the force of powder, or the strength that is required in different parts of the gun, be ascertained with any degree of precision, until the manner of the initial action of the powder is known.

When we consider how very defective is the old theory of gunnery, it is remarkable that no improve-

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into the muzzle; the reason being that no *time* is allowed to clear the obstacle away—although a very slight *pressure* would suffice for the purpose. Should rifled guns, for throwing iron shells, ever come into use, something might be done to diminish the first impulse of the powder, such as having the guns chambered, or by the employment of a different kind of powder.

ments of an important kind have been made in it for fifty or sixty years. This is probably in a great measure traceable to the opinion held by all military men, that the conclusions of Hutton and Robins are perfectly true and incapable of correction; thus adding another example to the many already existing, of the injury that is done to the cause of science and truth by a blind unreasoning deference to "authority." Whatever alterations have taken place in the practice of gunnery, and in the construction of ordnance during the last half century, may nearly all be traced to the difference in the quality of the powder at present, to that which was formerly in use;* as an attentive consideration of this question will show.

There are, at least, four elements of force to be considered in the action of fired gunpowder. 1st. That which proceeds from the sudden conversion of the powder into a fluid; 2nd. The elasticity of the fluid itself; 3rd. The elasticity of the fluid when heated to a certain temperature; 4th. The higher temperature which it retains, and also the *time* which is allowed for its more complete combustion, by confinement. The powder at present in use being a much stronger and a quicker burning powder than that which was formerly used, its initial action has, therefore, as regards all the above circumstances, a much higher value—its force, in fact, being more

* Appendix C.

concentrated; whence it follows that the guns of the present day require to be shorter and stronger.

Probably, if two kinds, one a quick, and the other a slow burning powder, were both completely confined, the whole force exerted by the latter, upon ignition, would be as great as that produced by the former; although the quick burning powder would exhibit a greater explosive, or fracturing force, owing to the more sudden exertion of its force. By using a quick burning powder in gunnery, we obtain (from its rapidity of conversion) a greater force in a smaller space. Thus, we see, in blasting, a quick burning powder is not so effective; since, the force of the charge being expended with a rapidity in proportion to that of the ignition of the powder, no time is allowed for overcoming the inertia of the substance required to be moved.*

Now the chief reason why gunpowder is preferable, as a projectile force, to all other explosive compounds, is

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* For this reason, a quick burning powder will be the best to employ for shattering or bursting open the gates of a town, or fortress. Piobert's experiment (page 190) suggests the idea that the effect of the explosion might be considerably heightened by opposing a plane surface to the action of the powder on the contrary side to that against which the force is directed. A flat iron screen, which the men might push or carry before them when placing a bag of powder, would serve both to protect them against musketry, and, (if it were afterwards left standing close to the powder,) to increase the effect of the explosion.

because its combustion is more *gradual;* and, although an extremely quick burning powder may be good for mortar practice, it is extremely questionable if it is so good for ordinary gun practice. In fact, the quickness of ignition may be carried, in this case, to too great an extent; for it may be increased to such a degree that no gun would bear the strain caused by the initial action of the charge.

It is hoped that these remarks will contribute, in some measure, to the improvement of what must be acknowledged to be a noble science; but it will require a long and careful series of experiments to perfect the theory of the action of fired gunpowder. It is, however, confidently thought, that the suggestions here made will indicate the proper direction for experimental enquiry, and lead eventually to most important results in the theory and practice of gunnery.

[The correctness of the foregoing theory may be tested in a very simple and conclusive manner, by the *recoil* of guns. If two guns, constructed of similar metal, one being exactly of twice the linear dimensions of the other, were fired with proportionate charges of powder, and (in other respects) under precisely the same circumstances, the *recoil* would show the force expended in each gun. The argument employed by Captain Boxer, that the fluid acted upon the shot (in my experiments) after it had left the chamber, and, therefore, that the experiment was not conclusive, could not possibly be brought forward in this instance; since the fluid, after it had once escaped at the muzzle, could not be supposed, even by the most inveterate quibbler, to act upon the gun in a

manner to increase the recoil. The recoil would, therefore, be a very conclusive test of the relative force exerted by the powder on each gun. (I am at a loss to understand, by-the-way, how Captain Boxer reconciles his argument, "that the fluid acted upon the shot after it had left the chamber," with the axiom, laid down by Robins, (*New Principles of Gunnery*, Prop. 7, p. 74,) and found in all works on gunnery (Captain Boxer's included) that "*the action of the powder on the ball ceases as soon as the ball is got out of the gun.*") A matter of this importance is surely a worthy subject for experiment; especially when the trouble and expense attending it would be so small.]

APPENDIX.

(A.)

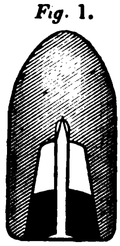
ELONGATED BULLETS FOR RIFLED MUSKETS.

THE form of the bullet, for rifled muskets, has undergone various changes during the last few years. For a detailed account of these different modifications, up to the present time, I cannot do better than refer the reader to two excellent little works, the "*Rifled Musket*," by Capt. White Jervis, and "*Rifle Practice*," by General Jacob; also to an extremely clever pamphlet on the "*Improvement of the Rifle*," by Lieut.-Col. Lane Fox.

The bullet at present in use, is, I believe, the invention of Col. Hay, and is found, in practice, preferable to that introduced by Pritchett. It is hollowed out more behind, so as to admit of a wooden plug being placed in it, by means of which the necessary *rapidity* of expansion (which is apparently wanting in the Pritchett bullet) may be obtained, and its centre of gravity thrown more forward. The objection to this bullet lies in the fact, that the plug is quite detached from it; this both tends to produce a certain expansion of the lower part of the bullet previously to its being used, and thus to occasion a difficulty in loading; and also renders it liable to shift its position. It appears to me, however, that these defects might

in some measure be remedied by attaching the plug to the bullet by means of an iron pin, as shown in Fig. 1, or by the additional use of two or more grooves or guides, as represented in Fig. 2, so that when the plug is driven forward, it must naturally be in a straight direction, and being fixed, it could not so easily shift its position or be accidentally driven in, and so cause a premature expansion; and when discharged, the expansion would be more efficient. The wooden plug being retained in the bullet (by the pin) after the discharge, will probably add to the efficiency of the bullet, as a deep hollow in the hinder part must be rather prejudicial than otherwise to its flight.

Fig. 1.



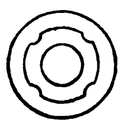


Fig. 2.

I would suggest, however, as a still better arrangement, the one shown in Fig. 3. This has a simple pin of iron, or other material, with a broad head. I have fired this bullet with excellent effect—it is both simple in its construction and effective in use.

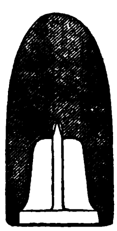


Fig. 3.

The real utility of a plug, or cup, in the bullet, is not that either one or the other should be driven up into the hollow, but in order to prevent the action of the powder upon the upper part of the hollow, and to allow the lower part of the bullet to be expanded before the inertia of the fore part is overcome; for the hinder part of the bullet having less solidity than the fore part, the lead there will be more easily *upset*, and it will thus expand and fill the grooves with greater rapidity than if the bullet were of solid lead. The chief cause of a bullet *stripping* arises from its not expanding with sufficient rapidity to fill the grooves previously to acquiring a certain velocity; it is probably for this reason that the Lancaster bullet is found occasionally to strip; as this bullet, being solid, cannot expand so quickly as the Enfield musket bullet. If the hinder part of the Lancaster bullet were constructed as in Fig. 3, it would not be so liable to strip, and any deficiency in weight, arising from the altera-

tion, might be made up by lengthening the bullet. The form of the Lancaster bore appears well adapted for muskets, from the absence of the angles in the grooves, so that the bore, having a smooth surface, could be kept much cleaner.*

An open hollow in the hinder part of a bullet, is prejudicial to a proper expansion, as it allows the inertia of the upper part to be overcome in the same time as that of the lower part, and if the hollow be broad and deep, the fore part of the bullet may be blown off. A loose cup or plug placed in the hollow affords no certain remedy for this, as it is apt either to shift its position, or to be driven forward with violence, and jam the sides of the bullet against the barrel; in which case, owing to the diminished surface presented by the hinder part of the bullet to the action of the powder, and the impeding friction, the fore part of the bullet is liable to be blown off, or the plug forced completely through it.

Bullets of increased length and diminished diameter are less liable to the above mishaps, and there is this to be said in favour of the use of such bullets, that they acquire—from their length—a greater expansion; and although they require a greater turn, yet the angle formed by the grooves with the axis of the bore, (with a turn of a given length) becomes less as the calibre is diminished. Thus the angle formed by a turn of 3 feet in a musket of a calibre of ·577 in. would be greater than that formed by a turn of the same length in a musket having a calibre of ·5 in. only; so that a greater turn may be used with the latter, without much increase in the *angle* of the turn, whilst the expansion of the longer bullet insures it against stripping. The lower trajectory, or less incurvated track of such a bullet subjects it also to a smaller *lateral* deviation.

There are many advantages attending the use of a bullet which

* The necessity of a quick expansion is very remarkable in expanding projectiles used for cannon. When the expansion does not take place with sufficient rapidity, deep furrows, caused by the flame of the gunpowder passing beyond the projectile, are distinctly visible in the bullet.

can be made to expand quickly. It may probably be found necessary to increase the difference between the diameter of the bore of the Enfield musket and that of the bullet, in which case a quick expansion of the bullet will be of the first importance. The accounts lately received from India, respecting the difficulty of loading—whether it arises, as appears likely, from the effects of the climate, or from some other cause, not otherwise to be remedied,—tend to shew that some alteration in the windage, or difference between the diameter of the bore and that of the bullet, will be absolutely necessary.

It is asserted that there is an advantage attending the employment of a *solid* lead bullet, from the soldiers—in case of their ammunition failing when on distant service—always being able to make their own bullets: but this is no reason why a solid lead bullet should be *always* employed in the service. Bullet moulds for casting solid lead bullets, in case of need, might form part of the regimental equipment, without prejudice to the use of a different kind of bullet for the ordinary service bullet. A solid lead bullet requires, moreover, a very fine quick burning powder.

Fig. 4.

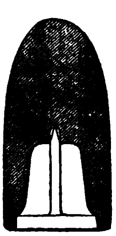


Fig. 4 has a plug, *a*, of tin, zinc, or other light metal, which is placed in the bullet when cast. This will throw the centre of gravity forward, and has the advantage of allowing the bullet to be of one piece. Bullets, however, being at present made by compression, their construction in this form renders them less eligible for military purposes than if made similar to the one represented in Fig. 3.

It is worthy of remark, that, in consequence of the bullets being made by compression instead of being cast, and from the centre of gravity being thrown forward, arises in a great measure the fact of the Enfield musket maintaining its position against many others possessing apparently superior advantages; since both the circumstances alluded to, allow of the use of a smaller turn, and consequently, less force is expended in imparting to them their rotary, as well as their translatory, motion.

(B.)

ON THE DEFLECTION OF LONG PROJECTILES.

THE theory, that the deflection, or *derivation* (as it is called) of rifled bullets is caused by the unequal pressure of the air consequent upon the bullet whirling about an axis which continues parallel to itself, and which forms an angle with its trajectory, so that the pressure of the air is greater upon the under, than upon the upper surface of the bullet (*see* plate 4, fig. 2), has been very generally entertained—with various modifications—since the time of Robins. Captain Tamisier, a French officer, who adopted these views, endeavoured to obviate the deflection of rifle bullets by constructing a bullet with circular grooves round its base; for the purpose of creating a resistance on the hinder part of the bullet; so that its apex should be brought down in such a manner that its axis would be a tangent to its line of flight, and the pressure of the air upon the surface of the bullet be thus equalized.

This, which has been called Captain Tamisier's theory, has been accepted by numerous persons; it is nevertheless very defective, as I will endeavour to show. In order, however, to do so, it will first be necessary to give some further explanation of it; for this purpose I cannot do better than quote Captain White Jervis's

little work on the Rifled Musket. After noticing the circumstance of the greater pressure upon the lower surface of a long projectile, when its longer axis remains parallel to itself; and the supposed effect of Captain Tamisier's circular grooves; he thus proceeds:—

"The lower side of the projectile, therefore, moving in the compressed air, and the upper in the rarefied air, deviations must ensue. For, as the upper part of the bullet moves from left to right, the bottom must move from right to left. But the lower resistance to the motion of rotation being produced by the friction of the compressed air, is greater than the upper resistance, which depends on the friction of the rarefied air. By combining these two resistances, there results a single force, acting from left to right, which produces what Captain Tamisier termed *derivation*, and it was to overcome this *derivation* that that officer proposed the circular grooves to the bullet, which he considered would act like the feathers of the arrow to maintain the moving body in its trajectory. By applying this new principle, bullets could be made of any form and length. * * * * *

Before, however, being able to seize all the consequences of this new principle, which consists in bearing out the theory of the air's resistance upon the cylindrical portion of the bullet to ensure its keeping the right direction, it may be necessary to enter into some details to give, if possible, a clear idea of this phenomena. When a spinning top is projected on the ground, animated by a very strong motion of rotation, it, first of all, leans very much on one side, then raises itself little by little, and, at last, finishes by turning round on its axis, which has become vertical, in such a manner as to make it appear motionless. What is the cause which induces the top to raise itself, and keeps it from falling? It evidently arises from the motion of rotation acted upon by the resistance of the air. For when the top leans on one side, whilst turning round rapidly, each portion of the lower part of its surface strikes successively, by virtue of the double motion of falling and of rotation with which it is endowed, the layers of the atmosphere with which it comes into contact; whilst the upper part of the surface comes, through this

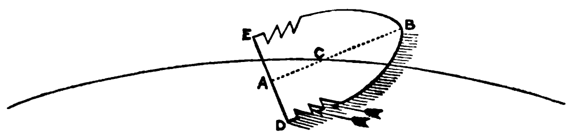
falling motion, into a part of the space formerly occupied by the body of the top, and has no resistance of the air to overcome to take up its new position, so that the force imparted to the lower portion, or rather to the inclined part of the surface of the top, is not neutralised by an equal force engendered on the opposite part.

"The resistance of the air tends, therefore, to raise up the top, and this resistance is greater in proportion as the motion of rotation is more rapid.

"If, however, we would wish to obtain some idea of the rotatory motion of a bullet in its path through the air, we cannot consider it in the same light exactly as a top spinning, for it is at the same time endowed with a force of progression.* But let us consider the action of the arrow which is only animated with this force of projection, and let us see how it is constructed, so that the resistance of the air should not act in an unfavourable manner against its action. First of all, nearly all its weight is concentrated at the point, so that its centre of gravity is close to it. At the opposite end feathers are placed, the heaviest of which does not affect the centre of gravity, but gives rise to an amount of resistance in rear of the projectile, and which prevents its ever taking a motion of rotation perpendicular to its great axis, and keeps it in the direction of its projection. This difficulty which the arrow finds in changing its direction must concur in preventing its descending so rapidly as it would do were it only to obey the law of gravity, and must therefore render its trajectory more uniform. We need scarcely add that the lengthened form of the arrow has precisely for its object to render as weak as possible the resistance of the air to the force of projection. Let us, however, now come back to the grooves of M. Tamisier, and we shall find that they concur in giving to the bullet the two actions of the resistance of the air which we have demonstrated with respect to the top and arrow.

* These theories of the top and arrow are generally supposed to have been started by Captain Tamisier, but they were originated by Robins. See his Mathem. Tracts, vol. i., p. 331. Edit. 1761.

"Suppose that such a bullet describes the trajectory M, and A B be the position of its axis, it will be seen that the lower part of the



bullet re-establishes the air compressed, whilst the upper part finds itself in the rarefied air. That consequently the lower part of the canelures is submitted to the direct action of the air's resistance, whilst their upper part totally escapes this action. The resultant of the air's resistance evidently tends to bring back the point of the moving body according to the trajectory; but as this action is produced by the pressure of an elastic fluid, it results that the point B, after having been an instant upon the trajectory, will fall below in virtue of the velocity acquired; but then the upper grooves, finding themselves acted on by the action of the air's resistance, this action, joined to its weight, will force the point of the projectile upwards, which will descend to come up again, so that the projectile will have throughout its flight a vertical swing, which is seen distinctly enough in arrows." (*Rifled Musket*, pp. 58—61.)

With regard to the latter observations, I feel disposed to doubt the fact of a bullet having a vertical swing, under any circumstances; as it is directly opposed to all that I have witnessed in my own experiments. I am not aware of an instance in which a bullet ever returned to its originial position after it was once compelled to alter it, excepting in the case of its turning completely over.

The flight of an arrow offers a very imperfect illustration of the flight of a bullet. The vertical swing occasionally observable in an arrow is generally owing to the propelling force not passing directly through the centre of gravity. It also arises from the arrow not being properly balanced, or feathered; and other circumstances, altogether distinct from those which operate in the case of a rifle bullet. Steadiness of flight in an arrow depends upon the nice adjustment of its parts, and the resistance created by the feathers; which are so placed that any tendency of the arrow to

rotate about its shorter axis is immediately converted into an inclination to rotate about the longer axis, and its steadiness is thus preserved. Steadiness of flight can only be given to a long bullet by imparting to it a sufficient rotary velocity about an axis situated in the direction of its flight.* This will give it a stability, which a resistance on the hinder part of the bullet—such as would be caused by Tamisier's grooves—would tend considerably to prejudice; since it is the peculiar manner in which the pressure of the air affects the *equilibrium* of long rotating projectiles (from

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* Robins's definition (which has hitherto been usually received as the correct one) of the action, and utility, of rifled projectiles, is as follows: " * * * * a bullet discharged from a rifled barrel is made to whirl round an axis which is coincident with the line of flight, and hence it follows that the resistance on the foremost surface of the bullet is equally distributed round the pole of its circular motion, and acts with an equal effort on every side of the line of direction; so that this resistance can produce no deviation from that line. And (which is still more of importance) if by the casual irregularity of the foremost surface of the bullet, or by any other accident, the resistance should be stronger on one side of the pole of the circular motion than on the other; yet, as the place where this greater resistance acts, must perpetually shift its position round the line in which the bullet flies, the deflection which this irregularity would occasion, if it acted constantly with the same given tendency, is now continually rectified by the various and contrary tendencies of that disturbing force during the course of one revolution."—(*Tracts on Gunnery*, p. 330.)

Recent investigation of the circumstances attending the flight of elongated projectiles, shews, however, that a rotary movement about an axis situated in the direction of its flight alone tends to keep the projectile in the plane of its trajectory; not because the pressure of the air is thereby equally distributed round the pole of the circular motion; but because the rotary movement gives a *stability* to the projectile, which enables it actually to *resist*, not only the oblique pressure of the air, but any other force which would tend to cause deviation, or unsteadiness of flight.

The "Gyroscope,"—a scientific instrument of somewhat similar action and make to the one used by Professor Magnus in his experiments—gives evidence of the great stability of the axis of a rotating body. Many interesting experiments may be made with this little instrument; the movements of a rotating body, when acted upon by a disturbing force, may be more readily ascertained by it than by any other means. The few experiments which I have made with it, tend completely to confirm the general correctness of the views entertained by Professor Magnus.

the direction of the force not passing through the centre of gravity*) which chiefly causes the *derivation*—the *obliquity* of the pressure in fact, which, by disturbing the equilibrium of the axis of the projectile, causes the action of the air to be stronger on one side than upon the other. Another, but slighter, cause exists, in the uneven surface of rifled projectiles; since, the pressure being greater on the lower than upon the upper surface, the projections will tend, to deflect the projectile from the vertical plane in various manners according to the position in which they are placed upon the surface of the projectile. But the theory, as hitherto received, that the deflection of long projectiles is due solely to the friction being greater upon the under, than upon the upper surface—from the angle which the axis of the projectile makes with its line of flight—is, without doubt, (except in so far as I have mentioned,) altogether erroneous.

The most efficient projectiles—as regards *accuracy*—will, undoubtedly, be those which are constructed—as to their external form, and the position of the centre of gravity—in such a manner, that, in passing over a given space, the pressure of the air shall produce the smallest disturbing effect upon the equilibrium of the axis

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* "If on a solid of revolution, whose axis is freely moveable in all directions, a force acts during its rotation with great velocity around its axis, and the direction of this force pass through the axis but not through the body's centre of gravity, a lateral motion will, as we know, take place; but its velocity is always very small, not only in comparison to the velocity of rotation, but also to the motion which the same force would have imparted to the axis had not the body rotated. On this account the axis appears to retain its position unchanged."—(*Magnus on the Deviation of Projectiles, and on a Phenomenon of Rotating Bodies.* Taylor's Scientific Memoirs, p. 230.)

From this it is manifest that the action of the air, whether from its actual resistance, or from the wind, will always produce one effect only upon a rotating projectile, namely, to give it a lateral movement in the direction of the turn; which movement will be slow, in proportion as the velocity of rotation is high. The action of the wind is, in general, too small to move a cannon shot bodily from the plane of its trajectory, but will always tend to increase the *derivation*, or the deflection in the direction of the turn, from whichever side the pressure acts. It is not improbable that this circumstance gave rise to Colonel Beaufoy's remark, that Robins's egg-shaped bullet flew to windward.

about which they rotate. I am inclined to think that—the rotary velocity being proportionate—the equilibrium, although perhaps more liable to be disturbed, will be disturbed in a manner the least likely to affect the accuracy of the projectile, when the centre of gravity is in a forward position; since the axis of a projectile so constructed (owing to the smaller cone which the fore-part will describe about the direction of flight; * and to the greater

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* When the centre of gravity is at, or behind the centre of the projectile, the cone will be described about an axis parallel to the direction of projection, or nearly so; but when it is in the fore part, it will be about an axis which is nearly tangent to its curve of flight; the disturbing force of the air, in the latter case, will therefore be less.

Professor Magnus supposes (from his experiments) that the axis of rotation of a long projectile always remains nearly a tangent to the curve throughout the whole flight; and that the apex is sometimes depressed even below the tangent to the curve of flight; but his description of the circumstances under which the projectiles were fired (in his experiments) is so vague, that it is impossible to form a correct opinion of the value of many of the results which he describes. He simply mentions that a very low velocity was given to the projectiles. The position of the centre of gravity—the rotary velocity—the form of the projectiles and the angle at which they were fired—all of which considerably affect the movement of the projectile, remain altogether unnoticed. A description of these circumstances might have enabled us to account for some of his results, which, at present, are difficult to reconcile with the observations of others.

The motion, during its flight, of a projectile which has an insufficient rotary velocity imparted to it, presents a very different appearance to that of another which acquires a proper rotary velocity; and when, in the former case, the projectile has the centre of gravity behind its centre of figure, the apex will appear (especially when the rotary velocity, and the angle of elevation are small) to be more depressed than that of another which has the centre of gravity in a forward position; since the cone, which the former describes about the line of direction, will be larger. If the apex of a properly formed projectile were ever really depressed below the tangent to the trajectory, the flight of long projectiles would not be so extended as we know it to be.

Therefore, although there can be no doubt that Professor Magnus's explanation of the effect of the air upon long rotating projectiles is substantially correct, as far as his experiments go, yet, inasmuch as those experiments are very imperfect, his description of the circumstances of the flight of a long projectile cannot be con-

pressure, in the same direction, on the part behind the centre of gravity) would not acquire so great an inclination to the vertical plane.

Probably the best formed projectile, for both range and accuracy, (especially when the angle of elevation is high,) will be such as have the centre of gravity sufficiently forward to maintain the axis nearly a tangent with the curve of flight; as, in this case, the retarding and disturbing force of the air will both be smaller.

When we consider the great pressure of the air, and that it must always act obliquely upon the projectile, it would appear impossible that the *derivation* can ever be completely overcome (except, perhaps, with shot fired with low velocities and a very quick turn), although with care it may be reduced in such a manner as to be easily allowed for, in a proper proportion, according to the elevation of the gun.

The spinning of a top is even a more unfortunate illustration to bring forward in support of Captain Tamisier's theory, than the flight of an arrow. A spinning top which at first leans very much on one side, is not kept from falling, or induced to raise itself, by the resistance of the air; but acquires a vertical position *solely* from the act of rotation and *the friction of its point against the ground, or surface upon which it is spinning;* and it *maintains* the vertical

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sidered as applicable to such as are constructed of a proper form for obtaining the greatest range and accuracy, and which have a sufficient rotary velocity imparted to them.

He shows that the form (especially of the fore part) of the projectile considerably affects the manner in which the equilibrium of the axis of the projectile is disturbed by the air—but fails to describe the form which will be productive of the least disturbance; in fact, his experiments appear to have been made with one or two kinds of projectiles only, and he could not, therefore, give a decided opinion upon this point. His experiments, however, possess a great value, since they show the actual manner in which a rotating projectile is deflected by the air; but he would have found many of the peculiar effects which he describes greatly modified, or, altogether absent, if he had fired a properly formed projectile, with a sufficient rotary velocity.

position in consequence of the remarkable stability acquired by the axis about which it is caused to rotate, which enables it to resist any attempt to disturb it;* and the greater the rotary velocity, the greater will be the stability which the axis of the top will acquire, and the longer it will maintain a vertical position. The resistance of the air tends to destroy the rotary motion, and is, therefore, prejudicial to the stability of the top. If we suppose a top spinning in a vacuum, it would maintain a vertical position for a much longer time, than if spinning in the atmosphere; and if, in the former case, a disturbing force were to cause it to lean over to one side, it would recover its vertical position in precisely the same manner, and for the same reasons that it would when spinning in the atmosphere.

If a top, spinning about an axis not quite vertical, were allowed to fall through a certain space to the ground, it would continue to rotate about an axis parallel to itself (supposing its centre of gravity to be at its centre,) until it reached the ground, *when it would first begin to acquire a vertical position.*

In the event, however, of its falling upon a perfectly smooth surface, the friction would not be sufficient to allow of the axis of the top assuming a vertical position; but the part *below* the centre of gravity (the centre of gravity, and not the point, being, in this instance, at rest) would describe a cone about the axis, in a similar manner to the part *above* the centre of gravity; and the circle described by the point would be continually larger, as the rotary motion diminished. The movement of a projectile, when the rotary motion is not sufficiently rapid to ensure a sufficient amount of stability to the longer axis of the projectile to enable it to resist the pressure of the air, is similar to this; in which case it rapidly turns over.

I am aware that this view of the question is contradictory to all elementary works on Natural Philosophy, and would, therefore seem to require some further explanation; but a complete mathe-

* The "Gyroscope" affords an admirable illustration of this.

matical investigation of the subject would be too long, and of too abstruse a nature for a work of this kind; suffice it to say, that the idea was originated by Mr. Sprague—a gentleman whose ability as a mathematician is unquestionable.

The following considerations, kindly furnished me by that gentleman, will be sufficient to shew those who are acquainted with the Mathematical Theory of the Composition of Rotary Velocities, that the friction of the point of the top upon the surface on which the top is spinning, really causes the axis of the top to assume a vertical position. Supposing a top to be spinning about an axis inclined to the vertical, upon a smooth surface, the action of gravity has a tendency to make the top rotate about a horizontal axis; or, in other words—to fall. It is well known, however, that, in consequence of the rotation of the top, it will not fall, but the new rotation which would be produced by gravity combines with the original one, and the effect is that the axis of the top about which it still continues to rotate, will slowly describe a cone about the vertical line, —the velocity with which the axis of the top revolves being less, as the velocity of rotation of the top is greater. Now, if the surface on which the top spinning is quite *smooth*, it will offer no resistance in a lateral direction to the motion of the point of the top, and therefore, in accordance with the elementary and well known laws of motion of a solid body, the centre of gravity of the top will remain at rest, while the point of the top will describe a circle on the surface, and the apex of the top will describe another circle in a parallel plane. If however the surface is rough, the friction introduces another force acting on the top, which will give it a tendency to rotate about a new axis, *perpendicular to the axis of the top, and in the same vertical plane.* This new rotation will combine with the former rotation of the top; and it will be seen, by considering the directions in which the various rotations take place, that the resulting rotation will be abont an axis less inclined to the vertical than the axis of the top, so that that axis will gradually assume a vertical position. In consequence of this, the apex of the top, instead of describing a circle, will

describe a diminishing spiral, till at last the axis of the top becomes vertical—the point of the top remaining at rest, or nearly so, during the motion.

The explanation of Captain White-Jervis, as set forth in the foregoing extract from his work, is quite erroneous. In fact, he has overlooked the circumstance that if his theory were correct, no sooner would the axis of the top begin to move towards the vertical, than the resistance of the air on that side would become greater, and the top would be driven back to its former position, or still further.

(C.)

IMPROVEMENTS IN ORDNANCE.

THAT the reader may form some idea of the progress which has been made in the use and the construction of cannon during the last two centuries, I have inserted a description of the different cannon in use, and a table of the ranges obtained with some of them, in the year 1646.

From this it will be seen that the chief improvement consists in the attainment of a slight increase in the effect, with a shorter and lighter description of gun. This advantage is principally owing to the improvement made, since the above period, in the manufacture of gunpowder; which (from its larger initial or explosive force) will now give a shot, when fired from a short modern gun, a velocity, which, formerly, was only to be acquired with a gun of great length, and the use of a much larger charge. And although the range of balls of equal weight remains, as will be seen, much the same, yet the means by which these results are obtained have been very much improved.

The extracts which follow are taken from a little work, to which reference has already been made, *The Gunner's Glasse*, by W. Eldred, who, for sixty years, was Master Gunner at Dover Castle. It should be observed that the powder in use at the period when

these ranges were taken, was "corn" powder, a (then) new description of gunpowder of greatly increased strength; being, as remarked by Eldred (*Gunner's Glasse*, p. 21), "twice as strong" as that which was used before his time. The powder which was in use previously to this period, and even then partly in use, was called "serpentine" powder, and was of inferior strength, and not granulated. Before the "corn" powder came into use, cannon were of enormous length; the demi-culverin, or basilisk, at Dover Castle, temp. Queen Elizabeth, is nearly 24 ft. (or 60 calibres) long; and, at Deal, there was, in Eldred's time, a "brasse" demi-culverin 16 ft. long.

The powder of the present day is "twice as strong" as that used in Eldred's time—the charges, in consequence, are now much smaller, and the guns, although comparatively stronger at the breech, of reduced length.

Table No. 1, is descriptive of the different pieces of ordnance in use two hundred years ago; No. 2 contains a more minute description of several pieces of which the ranges are given; and No. 3 is a table of the ranges, or "randons," (as Eldred calls them,) of these pieces.

These Tables are not transcribed exactly in the order in which they stand in Eldred's book, but are taken from different parts of the work. I have also taken the liberty of making various small alterations—such as reckoning the ranges in yards, instead of by miles and scores—in order to render the tables more simple.

It will be observed that the *windage* was very large, and that the same quantity (½ in.) was used with each description of gun.

No. 1.

A TABLE OF THE HEIGHT AND WEIGHT OF PIECES.

The Names of the Pieces.	The Calibre or height of the Bore.	The Weight of the Shot.	The Length of the Piece.	The Weight of the Piece.
A Rabonet . . .	$1\frac{1}{4}$ in.	$\frac{3}{4}$ lb.	3 ft.	120 lb.
A Falconet . . .	2 in.	$1\frac{1}{4}$ lb.	4 ft.	210 lb.
A Falcon	$2\frac{3}{4}$ in.	$2\frac{1}{4}$ lb.	6 ft.	700 lb.
A Minion	3 in.	4 lb.	8 ft.	1500 lb.
A Saker.	$3\frac{1}{2}$ in.	$5\frac{1}{4}$ lb.	$9\frac{1}{2}$ ft.	2500 lb.
A Demy-Culverin	$4\frac{1}{4}$ in.	9 lb.	10 ft.	3600 lb.
A Whole Culverin	5 in.	15 lb.	11 ft.	4000 lb.
A Demy-Cannon .	6 in.	27 lb.	12 ft.	6000 lb.
A Whole Cannon .	7 in.	47 lb.	10 ft.	7000 lb.
A Cannon Royall .	8 in.	63 lb.	8 ft.	8000 lb.

No. 2.

	Falcon. Brass. 1	Falcon. Brass. 2	Falcon. Iron. 3	Sacar. Brass. 1	Sacar. Iron. 2	Demi-Culv. Iron. 1	Demi-Culv. Iron. 2	Wh[illegible] Culv Iron. 1	
The height of the Bore .	2¾ in.	2¾	2¾	3⅛	3⅛	4⅛	4¼	5¼	
The height of the Shot .	2⅝ in.	2½	2⅝	3¼	3¼	4¼	4	5	
The weight of the Shot .	2 lb.	2 lb.	2 lb.	5 lb.	4lb. 12oz.	10 lb.	8lb. 11oz.	17lb. 5oz.	
The weight of the Powder	2 lb.	2 lb.	2¼ lb.	4 lb.	4 lb.	7 lb.	7 lb.	9 lb.	8 [illegible]
The length of the Cartridge	7 in.	7 in.	8 in.	10 in.	10 in.	17 in.	17 in.	19 in.	18 i[illegible]
The length of the Dispart.	2¼ in.	2 in.	1¾	3¼	3¼	3¼	3¾	3½	2¾
Fortified in the Chamber .	2¾ in.	2 in.	3 in.	3½	5½	5¼	6 in.	6¼	5¾
The length of the Piece .	6 ft. 1 in.	6.6	6.6	9 ft.	9.9	10.2	10.8	10.9	16 ft.
The weight of the Piece .	700	800	1100	1600	2700	3500	4000	4600	4200

No. 3.

A TABLE OF RANDOMS, OR RANGES.

Angle of Elevation.	Falcon.	Saker.	Demi Culverin.	Whole Culverin.
	Yards.	Yards.	Yards.	Yards.
Lev.	320	360	400	460
¼		405	450	515
½		450	500	570
¾		495	550	625
1	480	440	600	630
2	640	720	800	900
3	800	910	1000	1120
4	960	1090	1200	1330
5	1120	1270	1400	1460
6	1280	1450	1600	1770
7	1440	1630	1800	1990
8	1620	1810	2000	2210
9	1760	1990	2200	2430
10	1920	2170	2400	2650

"*The Gunner's Glasse*" is well worth the perusal of all who take an interest in the subject of gunnery, and would be an excellent work for Military Libraries; both for the purpose of shewing the state of gunnery two centuries back, and, "though it appears a little

out of fashion," for the good advice which it contains; the author being evidently one who was accustomed to "put his trust in Providence, and keep his powder dry."

The second part of the book need not necessarily be reprinted, as it contains only the opinions of Diego Ufano, Captain of the Artillery of Antwerp Castle, with reference to matters in connection with the warfare of the period. The first part (about 110 pages) might be transcribed and reprinted, with the woodcuts, at a cost of about 30*l.* or 40*l.* The only copy which I have yet seen is in the British Museum.

LIST OF WORKS, *to which reference has been made in the foregoing Treatise, with the dates of their publication.*

The Gunner's Glasse, by W. Eldred 1646
New Principles of Gunnery, by Benjamin Robins (new edition, corrected by Dr. Hutton) 1805
Scloppetaria, by a Corporal of Riflemen (Col. Beaufoy) . 1808
Mathematical Tracts, by Dr. Hutton 1812
Cours d'Artillerie, by General Piobert 1841
Experiments on Gunpowder, by Major Mordecai, U.S.A. . 1845
Taylor's Scientific Memoirs 1853
Artillerist's Manual, by Major Griffiths, R.A. 1854
On the Science of Gunnery, by Captain Boxer, R.A. . . 1854
On the Rifle Musket, by Captain White-Jervis, R.A. . . 1854
Naval Gunnery, by Sir H. Douglas 1855
Treatise on Artillery, by Captain Boxer, R.A. 1856
Rifle Practice, by Lieut.-Col. Jacobs 1857
On the Improvement of the Rifle, by Lieut.-Col. Lane Fox 1858
Etude sur les Canons Rayés, par le Captne. F. Gillion . . 1858
On Mechanical Subjects, by J. Whitworth, F.R.S. . . 1858
Philosophical Transactions of the Royal Society
Mechanics' Magazine

London: Printed by W. CLOWES and SONS, 14, Charing Cross.

ADDENDA.

ON THE NATURE OF THE ACTION OF FIRED GUNPOWDER.

THIS subject has lately excited so much controversy that I am induced to offer a few further remarks upon it; the more so, as the theory put forward in these pages appears to have been completely misinterpreted by many persons.

The question of the action of fired gunpowder embraces two distinct considerations, which require each a separate investigation:—1stly, there is the chemical action which takes place on the application of heat; and, 2ndly, the effect produced by the explosion of a given quantity of powder when confined in a chamber of given dimensions.

In the preceding paper I limited myself to the consideration of the latter effect only, since the force which we have practically to deal with (in gunnery) is that which is exerted against the sides of the chamber

of a gun and upon the shot. This force, as I then attempted to show, (contrary to received opinions) varies with the quantity of the powder and other circumstances.

It has hitherto been assumed that the initial pressure of the fluid against the sides of the chamber and upon the shot is constant in amount, and equal in all directions; but these are propositions which are not borne out by experiment.

It is evident that when the fluid of fired gunpowder is excited to action by the agency of heat, a great commotion must take place in the chamber of the gun; and that the magnitude of the effect then produced must mainly depend upon the number of the atoms of the fluid which are set in motion in a given space* and in a given time, and upon the celerity with which the whole charge is affected by the heat.

* "All gases and vapours are assumed to consist of numerous small atoms, moving and vibrating in all directions with great rapidity; but the average velocity of these vibrations can be estimated when the pressure and weight of any given volume of gas is known, pressure being, as explained by Joule, the impact of those numerous small atoms striking in all directions, and against the sides of the vessel containing the gas. The greater the number of these atoms, or the greater their aggregate weight, in a given space, and the higher the velocity, the greater is the pressure. A double weight of a perfect gas, when confined in the same space, and vibrating with the same velocity—that is, having the same temperature—gives a double pressure; but the same weight of gas, confined in the same space, will, when the atoms vibrate with a double velocity, give a quadruple pressure."—*Encyclop. Brit. 8th Edit. Art. Steam.*

The exact nature of the action which takes place can only be ascertained by proper chemical analysis; but whatever its nature, it is clear that there must be a certain quantity of mechanical work performed,—that is, a pressure must be exerted through a certain space,—before the fluid can exert any pressure against the sides of the containing chamber; and that the value of the pressure which then takes place must depend upon the quantity of work performed in a given space and time.

The amount of force which is exerted by different quantities of powder in guns of different sizes, appears to be a question of the *magnitude of the pressure at a given time*, rather than (as ordinarily supposed) of the *time of action of a given pressure.*

In the absence of any fixed or reliable *data* concerning the chemical action which takes place during the combustion of a charge of powder, I offer the following propositions for consideration; not as affording the most complete or satisfactory solution of the question of the relative force of different charges of powder, but in the endeavour to account, in some manner, for the fact—which I believe to be indisputable—that the force of powder attains a much higher magnitude in large guns than in small.

Firstly, That the *initial pressure* of the fluid of fired gunpowder upon the sides of the chamber of a gun, or upon the shot, s in proportion to the *relative amount of 'work' done previously*, or to the momentum acquired by the particles of fluid in passing through a certain

space—and will therefore vary according to the rapidity of combustion of the charge or quantity of fluid set in motion in a given time, the heat, density, and velocity of the fluid, and the celerity with which the whole is affected by the degree of heat—before the action of the fluid takes place upon the sides of the chamber, or, upon the shot.

Secondly, that the *whole force* of the explosion of a charge of powder is represented by the *amount of work which must be done before the particles of fluid can be brought to a state of rest.* This force, therefore, can only be measured by the resistance which would be necessary to bring these particles to rest.*

From the first of these propositions it will follow, that the amount of initial pressure will depend upon the size and form of the chamber, upon the quality and disposition of the powder, the manner of its combustion, &c.; and from the second, that the amount of pressure exerted against the sides of a containing vessel of a given size, during a given time, will depend—up to a certain limit—upon the nature of the resistance which is offered to the motion of the fluid during that time. Thus may be explained the circumstance that when

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* If we suppose a quantity of the fluid brought to a state of quiescence in a chamber, it would then—and not till then—exert a uniform pressure in all directions, in proportion to its density and elasticity; and this pressure is practically considered, in all works on Gunnery extant, to be the only force produced by fired gunpowder.

powder is not free to expand, or is completely confined, it exhibits a force so much superior to that which is assigned to it by persons who have formed their estimate of its force from the effect produced upon a shot only. It is one of many circumstances which admit of no reasonable explanation by the ordinary theory. The only doubt which at first existed in my mind respecting the truth of the proposition that an increased resistance causes a greater exhibition of force, arose from the circumstance that when in my experiments I placed a larger shot upon a small chamber, there was no appreciable difference in the amount of force produced in the charge—but this can be explained by the circumstance that the initial action of the powder was so violent that the difference in the time required simply to move the larger shot was inappreciable.

The combustion of gunpowder, although extremely rapid, is gradual. It follows, therefore, that the number of particles of fluid set in motion in a given time, must vary both with the quality of the powder, and with the size and form of the chamber. This was clearly shown in my former experiments, for, when the linear dimensions of a similar chamber were increased to twice the size, a shot of eight times the weight was moved to exactly twice the height. In this instance the quantity of powder was increased eight times, but the distance, in each direction, to be traversed by the flame, was only twice as great. Now, as the increase in the distance traversed by the flame was only one-fourth,

as compared with the increase in the quantity of powder, relatively only one-fourth of the time could have been occupied in the ignition of the charge; or, four times the quantity was ignited in relatively the *same* time; so that the amount of work done in the same relative time must have been quite four times as great: and although the surface acted upon was relatively but half as great, yet the pressure in this instance being comparatively four times as great, the motion communicated to the shot was comparatively twice as great; thus, the large shot actually acquired a higher velocity in the *same space of time.*

Thus may be accounted for the different estimates formed by various writers of the initial force of fired gunpowder; the experiments of some having been made with guns of small, and, those of others, with guns of large calibres. The pressure exerted in the chambers of very large guns (especially when rifled, and when the friction produced by the first movement of the projectile is great) will be found, I believe, of much greater value than any which has yet been assigned to the initial pressure of fired gunpowder, except that which was given by Count Rumford.

It may naturally be asked how it happens that the considerable difference in the force of gunpowder which is exerted in the chambers of guns of different sizes, was never discovered before; but this is easily explained. A very limited number of persons have interested themselves sufficiently in the question to

make experiments upon it, and those who have made experiments, have drawn their ideas, and made their calculations, of the initial effect of powder upon shot, chiefly from observing the *whole* effect produced by the powder upon the shot when fired from guns of different calibres; and not from observing the effects produced in chambers containing a quantity of powder only. The discovery of it by myself (which led to my experiments) was purely accidental.

Now, since the work done in the chamber of a large gun before the shot is sensibly moved, is relatively much greater than the work done in the chamber of a small gun, it follows that the whole time of action of the charge will be relatively of shorter duration; hence *length* (in calibres) is not of the same importance in large, as in small guns. There are also other reasons why an addition to the ordinary length of large guns adds very little to the velocity acquired by the shot. It is well known that the expansive power of the elastic fluid is enormously increased by the heat which attends the combustion of the powder; * now, the first impulse given to a large shot being greater, it is moved through the first portion of

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* The temperature in large guns is probably heightened from the comparatively greater density of the fluid in the chamber, arising from the more rapid and complete combustion of the powder; there is no doubt that the latter produces a higher velocity in the motion of the particles of fluid.

the bore with greater rapidity, and, consequently, the temperature falls much more rapidly than is the case in smaller guns, so that the quantity of energy lost in the same time is comparatively much greater, and the accelerating force of the powder is thus considerably diminished. Also there is a greater degree of resistance at first offered to the motion of the fluid, and consequently a more rapid expenditure of force.

Robins' experiment of placing the ball in a musket, at some distance from the powder—under which circumstances he obtained a velocity of 200 feet a second greater than when the ball was placed in immediate contiguity with the charge—may be explained by the circumstance, that the momentum or moving force acquired by the particles of fluid before they encounter the ball is much greater when the ball is placed at a little distance from the charge; consequently, a higher velocity will be acquired by the shot in a given time. But the distance at which the shot can be placed from the charge, with increased effect, will vary with the length of the gun and the quantity of powder contained in the charge.

In the same manner may be explained the circumstance that when (in my own experiments) I increased the *depth* only of the chamber, and then filled it with powder, the same ball was driven to a much greater height; the fluid acting through a greater space before it took effect upon the shot, time was allowed for the more complete combustion of the

powder; and therefore the motion of the fluid was considerably accelerated, and the impulsive action increased.

It is remarkable that so many persons should have misunderstood my meaning, when I stated that the first action of the powder on the shot was impulsive, or percussive. One gentleman has observed that I reject altogether the notion that the force of powder is due exclusively to the gas it generates, and assume an additional impulsive force: another, that I believe powder, independently of the pressure exerted by its freed gases, exerts instantaneously a force of its own; and another, that I had stated that gunpowder had some mysterious action; that before the gases acted upon the shot, there was some kind of oscillation or undulation, which by some means communicated an initial velocity to the shot irrespective of their expansive action.

All such remarks are answered very simply, and as I think conclusively, for my experiments *prove* that the shot acquires a considerable velocity before it has moved to an appreciable distance. If the results of my experiments are admitted, this follows inevitably, and the only proper course for those who doubt my conclusion is to repeat my experiments. I feel well assured that after doing so, they will be forced to admit the accuracy of my conclusions. I did not put forward anything to explain the above result, for I was convinced that we did not know sufficient of the action that takes place in the conversion of the powder into vapour to

form a theory with any reasonable prospect of its being supported by further investigations. I simply said that the theory, at present received, is false, and is not an approximation to the truth. That theory in fact supposes that the action is the same in all respects as if the powder were compressed gas, which expanded in the usual way, and omits all notice of the chemical action that takes place in the conversion of the powder into vapour.

However, practically, it is of so little consequence whether the shot be supposed to acquire its initial velocity instantaneously, *i. e.*, by an impulsive action, or by the exertion of a very large pressure for a very short time, and through a very small space, as to be beneath consideration; and that the shot *does* acquire a finite velocity in a space equal to the small fractional part of an inch, and by the application of a force continued for so short a time as to be quite inappreciable, is shown by my own, and other experiments. Such a force is called, in mathematical language, an impulse, and this is all I have meant by using the term impulse.

It was shown by my experiments, that a shot of twice the diameter of another (the charge of powder being proportional and the quality the same), acquired, in a space so small as to be inappreciable, a velocity which caused it to move through a space equal to its own diameter in a shorter time than was required for the smaller shot to pass through an equal space—a fact

directly opposed to all existing ideas on the subject; hence the increased strain upon large guns, and the shorter proportionate space that large shot move through in acquiring a given velocity. That the time required to move a shot is really inappreciable, appears from the circumstance (noticed in page 184), that when the large shot was placed upon the smaller chamber, the effect produced by the powder was no greater than when the smaller shot was placed there; the weight of the larger shot being in this instance, more than eight thousand times greater than that of the charge of powder; a fact which goes far to prove that a very much greater bursting effect is produced in a gun by an increased quantity of powder, than by an increase in the weight of the shot, provided the latter is free to move in the gun. It should also be noticed that when the smaller shot was placed on the larger chamber there was no appreciable difference either in the time of action, or in the force exerted.

As to the objection that there is no possibility of a shot acquiring an initial velocity, I would answer, that the circumstance that all bodies require *time* for the acquirement of any kind of motion, is one of which I am quite aware, but where the time is too small to admit of its being taken, practically, into consideration, no notice need be taken of it. Mathematicians may, no doubt, prove very satisfactorily that the circumference of a circle is composed of an infinite number of straight lines, but ordinary purposes are better

answered by our accepting it as an axiom, that any portion of the circumference of a circle is an *arc of a circle*. This refining upon terms only leads to controversy and is much better abstained from.

It is singular that all who have done me the honour to notice my work have, without exception, overlooked the circumstance of the difference in the action and effect of powder described as taking place when the chambers differ in ***size***. The ***impulsive*** action of gunpowder has been noticed by previous writers (already enumerated), but the theory of the difference in the degree of force exerted upon the sides of the chamber, before the shot is moved, when the sizes differ, is entirely new, and totally opposed to the received *formulæ;* * all writers, without exception, having assigned a constant (but each one a different) value to the initial pressure upon the shot, irrespective of the size of the chamber.

The *form* of the chamber will also make a considerable difference in the action of a charge of powder. Thus, a chamber may be so formed (such as being slightly contracted towards the aperture) that a larger initial force may be obtained with a smaller quantity of

* In a small elementary work on Artillery, by Capt. Boxer, R.A., lately published for the use of the Military College at Sandhurst, the author, who strenuously opposed the idea when first started by myself, admits the fact, that the initial force of the powder varies with the calibre of the gun.

powder; but this would only be of advantage in mortars or extremely short guns, for the action along the bore is less forcible, since the actual amount of the whole force of a given quantity of powder cannot be increased, or, if at all, very slightly.

It has been considered by some to be advantageous that the first movement of the shot in the gun should be retarded by increasing the friction of the shot against the sides of the gun; but this is a great error. It is true that a larger force is obtained in a smaller space, but this force is expended upon the sides of the gun and in overcoming the friction of the shot, and in a gun of great length of bore a large amount of force would thus be altogether lost, or, what is worse, would tend to increase the recoil and the bursting effect upon the gun; but if the length of the gun were considerably reduced and an equal charge fired, then the retardation of the shot in the gun might perhaps be productive of some slight advantage. The absence of windage, however, (with expanding shot) compensates, in some measure, for the loss of power from friction.

It is a common error to suppose that the elastic fluid produced by the combustion of gunpowder, acts with a pressure which is inversely as the space occupied by it. The action, on the contrary, is more violent in proportion to the nearness to the seat of the explosion. This arises from the greatly diminished heat of the gases, and is evident from experiment, since it is shown that *length* is of much less consequence in large guns

(where the initial action of the charge is greater) than in small. If a charge of powder were supposed to be completely confined in the chamber of a gun of sufficient strength to contain it, what would be its action? Its force would gradually increase as combustion took place until it reached a *maximum*, when it would gradually diminish; its chief, or *explosive*, force would then be expended, and could not be renewed.

The greatest result would naturally be produced with powder which would exert the greatest amount of force for the greatest space of time. It by no means follows that the quickest burning powder will have this effect; for as only a portion of the force of a charge of powder is exerted before the shot is moved, and as the amount of this initial force will depend upon the quality of the powder, the action of a quick burning powder although greater at first will not be maintained for a sufficiently long time for the shot (except in a short gun) to acquire so high a degree of velocity as when the action of the powder is slower. Thus, although a fulminating powder, much exceeding the strength of gunpowder, would act with many times the initial effect upon the shot, still, its action would be so rapid, that its strength would be exhausted in its first effort, and there would be no time for the shot to acquire that velocity which would be obtained by the employment of a powder of a less impulsive kind. The experiment has been made, and with the result I have already mentioned.

When the bore of a gun is larger or smaller in diameter—of greater or less length—when a large amount of friction attends the shot's passage, or the commencement of its passage, through the bore of the gun, a different quality of powder may be advantageously employed.

If a slower burning quality of powder were employed, its *bulk* should not be sensibly increased; that is, it should not occupy too much space in the gun, otherwise a large portion of its energy might be wasted. To illustrate this, suppose a chamber of very great length (say six feet) and but half an inch in diameter; if such a chamber were filled with powder, and the powder ignited at one extremity, the action of the fluid would be so much greater at that end that, if the sides of the chamber were not strong, it might burst through them before its action at the other extremity of the chamber would be perceptible. In a similar manner we may account for the effect obtained by Hutton in some of his experiments. He states that when he increased the charge of powder to a very large quantity, the velocity acquired by the shot was smaller, whilst the *recoil* was greatly increased. No greater proof of the error of the ordinary theory of the action of gunpowder could be required than this; for if we suppose a shot acted upon by a fluid exerting (as assumed) a uniform initial pressure, it is true that its velocity would, in the above case, be smaller, since the action would take place through a shorter distance—but as action and

reaction are equal, the *recoil of the gun* would be in proportion to the velocity acquired by the shot; now according to the views which I have here put forward, an enormous pressure may be exerted upon the gun without a proportionate velocity being acquired by the projectile.

The work done upon the *shot* should be as great, and upon the *gun* as small, as possible, and the powder which produces this result in a gun of given dimensions, is the best.

Suppose the bore of a gun to be filled with a gas exerting a uniform pressure of a very large magnitude, and closed at both ends; take away the obstruction at one end, and the gas would escape, but the dynamical effect produced upon the gun would be comparatively small. But fill a portion only of the bore with the gas, and place a ball before it, and the gun would have a recoil in proportion to the velocity acquired by the shot in moving through the bore: and that quantity of gas which would give the highest velocity to the shot, would cause the greatest recoil in the gun, and *vice versâ;* so that by either increasing or diminishing the quantity of gas the recoil would be lessened. I would simply ask, then, how can the increase in the recoil which takes place at every increase in the charge of powder, be accounted for by the ordinary theory?

The difference between the ordinary theory and the one now put forward may be summed up in two words; the former is based upon *hypothesis*, and the latter

upon *fact*. The former theory supposes no intermediate action to take place between the first ignition of the charge and the movement of the shot, but supposes that a chamber filled with a quantity of powder becomes, in a mysterious manner, suddenly and completely occupied by a permanently elastic fluid exerting a uniform pressure on all sides. The latter, on the contrary, assumes that an intermediate action *does* take place, and that of a most violent character; and further, that upon the manner in which this commotion is produced, depends entirely the amount of pressure first exerted upon the shot and upon the sides of the chamber, as well as the nature of that pressure.

It appears incredible that the old theory could have been put forward, except for the purpose of affording a kind of basis for certain *formulæ;* but that it should be received "*au pied de la lettre*" as it now is, appears still more incredible.

In conclusion, I would state that I claim to have discovered and established, by my experiments, first, that the pressure produced by the fluid of fired gunpowder upon a shot, or upon the chamber of a gun, in no way resembles the uniform pressure of a confined gas, as assumed by the ordinary theory, but that, from its previous action through a given space, it acquires an impulsive or percussive character.*

* Some doubt has been raised as to the novelty of this proposition. It is true that Capt. Boxer, R.A., in a lecture which he

Secondly, that owing to the gradual combustion and decomposition of the powder, the pressure of the fluid has never, at the different periods of its action in a gun, the *same* value, but that it gradually rises to a certain magnitude, and then (when the shot has begun to move) gradually diminishes.

Thirdly, that (the charges being proportional) *the height to which the pressure rises in each gun varies with the size of the gun; and that it increases,*

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gave on the Science of Gunnery, in March, 1854,—advanced an opinion very similar to this; but as he made no attempt to verify or establish an opinion so subversive of the ordinary theory, or even to notice it in his subsequent Treatise on Artillery, and as I was quite unaware, when I first put it forward, that such an opinion had ever been entertained before, I do not hesitate to class the above amongst those facts which I consider to have been discovered, as well as established, by my experiments. I consider also that those who first see the practical application of an idea, and act upon it, are entitled to be considered the real discoverers.

Had it been possible for Captain Boxer to have spared from his official duties, as Superintendent of the Royal Laboratory at Woolwich, sufficient time to sift the question thoroughly, or to conduct the experiments which would have been necessary for that purpose, he would then probably have anticipated all that I have done, and no doubt have made further progress towards a solution of the question; but, as remarked before, he made no attempt, either to prove the truth of his proposition by experiment, or to apply it in any way to the practice of gunnery. As the trouble and expense of the only experiments which have been made with a view of substantiating the idea which I had conceived —as I can prove most clearly—equally with himself were borne by me, he cannot, I think, with any show of reason, claim that idea as his own.

in a high ratio, with any increase in the size of the gun.

It may also be inferred that the pressure, when at its highest in a gun, can seldom attain so high a magnitude—from the absence of time for its full development—as that which gunpowder could possibly exert, namely, that which it would acquire were the shot either not allowed to move before it at all, or to a very short distance from the charge only; but that, as the size of the gun, the friction (in rifle guns) produced by the shot, the quantity of powder, and rapidity of its ignition, are increased, it continually approaches that limit.

The manner in which I have attempted to account for the results obtained by experiment may, or may not, be correct, and mathematicians may cavil at the terms I have employed: the estimate also of the relative difference in the pressure exerted by different quantities of powder, &c. may, or may not, be perfectly exact; but this in no way alters the broad facts, which at least have the appearance of being sufficiently established by my experiments, not only to merit attention, but—if the science of gunnery be of any importance at all—to render it absolutely necessary that they should, at as early a period as possible, be either accepted, or (if not borne out by further experiment) rejected. Upon their reception or rejection depends entirely the course to be pursued in future with regard both to the construction of large guns, and the quality of the powder which should be used with them.

The introduction of rifled cannon into our service, renders it a matter of the highest importance that the whole of the *formulæ* in gunnery which refer to the action and force of gunpowder should be revised; and that proper experiments should be made for this purpose.

I would therefore strongly urge the expediency of making experiments, as well for ascertaining the relative force exerted by different charges of powder, as the effect produced by increasing the weight of the shot, and by the retardation arising from the friction of rifled shot; so that we might have, at least approximately —which is far from the case at present—some idea of the relative strength required for guns of different kinds and calibres. The science of gunnery is in that state that practice has gone a-head of theory, it is therefore evident, that—for real progress to be made—a further knowledge of *cause* must be acquired, as well as of *effect*.

If nothing else is done, it appears at least indispensable that the careful and scientific experiments of Dr. Hutton should be repeated with the rifled guns now in use in the service, in order that we may learn their exact capabilities, the circumstances under which they may be most advantageously employed, the charges and the quality of powder which conduce most to their efficiency, and other circumstances of the greatest practical importance.